United States Court of Appeals

for the Second Circuit

SUPPLEMENTAL APPENDIX

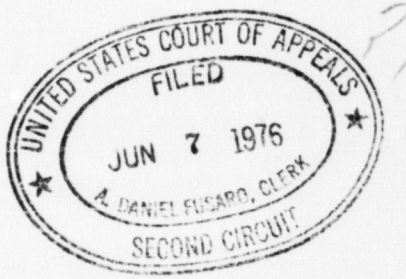
75-6115

76-6022

76-6081

IN THE UNITED STATES COURT OF APPEALS
FOR THE SECOND CIRCUIT

Docket Nos.
75-6115
76-6022
76-6081



THE STATE OF NEW YORK,

Plaintiff-Appellant,

-against-

THE NUCLEAR REGULATORY COMMISSION, et al.,

Defendants-Appellees.

ON APPEAL FROM THE UNITED STATES DISTRICT COURT
FOR THE SOUTHERN DISTRICT OF NEW YORK

SUPPLEMENTAL APPENDIX
VOLUME II

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NUREG-0034

DRAFT ENVIRONMENTAL STATEMENT

ON

THE TRANSPORTATION OF RADIOACTIVE MATERIAL BY AIR AND OTHER MODES

Docket No. PR-71, 73 (40 FR 23768)

MARCH 1976

U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF STANDARDS DEVELOPMENT

SUMMARY AND CONCLUSIONS

This Draft Environmental Statement was prepared by the U.S. Nuclear Regulatory Commission (NRC) , Office of Standards Development (the staff), Washington, D. C. 20545. Mr. Donald R. Hopkins is the USNRC Task Leader for this statement (telephone: 301-443-6910).

1. This action is administrative.
2. This Draft Environmental Statement has been prepared in connection with the NRC re-evaluation of its present regulations governing air transportation of radioactive materials, to provide sufficient analysis to determine the effectiveness of the present rules and of possible alternatives to those rules.
3. Summary of the environmental impact of radioactive material shipments in all modes of transport under the regulations in effect as of June 30, 1975:

   -Radiation exposure of transport workers and of members of the general public from normal, permissible radiation on the outside of packages in transport. This population exposure is estimated at 9600 person-rem per year, producing no short term fatalities, but on a statistical basis may produce one latent cancer fatality per year.

   -Potential radiation exposure of transport workers and of members of the general public in the vicinity of transportation accidents which involve radioactive material shipments. Looking at the entire spectrum of potential accidents, considering the probability

and consequences of releases of radioactive material in those accidents, the average radiological risk is shown to be very small, estimated to add only about one latent cancer fatality in two thousand years to the total risk.

-In contrast, in the very unlikely event of a major release of plutonium oxide in a densely populated area, there could be severe radiological consequences for a few individuals, with one early fatality and exposure for up to 16 others sufficient to produce death from cardiopulmonary insufficiency in some cases. The latent cancer fatalities statistically associated with this major release are estimated at twenty per year over a thirty year period. The probability of such an event is estimated to be 10^{-9} per year for 1974. It should be noted that for the above result to be obtained, all of the following conditions are necessary:

a. A low-probability, extra-severe accident, one which occurs only once in a billion miles of air-cargo service, must involve an aircraft carrying a bulk shipment of plutonium oxide. There are presently less than 100 bulk shipments of plutonium per year, most of which are transported by truck where extra-severe accidents are one hundred times less likely;

b. One or more of the plutonium packages, which are designed to withstand severe accident conditions, must be subjected to the highest of the forces developed in the accident so as to cause gross failure of the package and a subsequent release of a large fraction of the radioactive contents from the package;

c. The accident must create conditions which release a significant amount of the plutonium powder from the vehicle in which it was being transported and into the air such that the plutonium becomes airborne;

d. The meteorological conditions at the time are such that the plutonium remains airborne and is dispersed, and large numbers of people breathe the air which still contains the plutonium in high concentrations; and

e. Mitigating actions, such as evacuation of persons from the area, are not taken.

-Non-radiological impacts from the use of resources for packaging materials and from the use of , and accidents involving, a relatively small number of dedicated transport vehicles, were found to result in two injuries and less than one accidental death per year, and to otherwise be negligible.

4. Principal alternatives considered:

-Transportation mode shifts for various components of the industry.

-Operational constraints on transporting vehicles to minimize accidents.

-Changes in packaging requirements to minimize release of radioactive materials in an accident.

-Changes in the physical properties of radioactive materials to minimize consequences in the event of a release.

5. The following Federal, State and Local Agencies are being asked to comment on this Draft Environmental Statement:

   -Department of Commerce

   -Department of Health, Education, and Welfare

   -State and Local Agencies identified in Appendix H

   -Department of the Interior

   -Department of State

   -Energy Research and Development Administration

   -Department of Transportation

   -Environmental Protection Agency

   -Federal Power Commission

6. This Draft Environmental Statement was made available to the public, to the Council on Environmental Quality, and to the above specified agencies in March, 1976.

7. On the basis of the analysis and evaluation set forth in this statement, after weighing the very small adverse environmental impacts resulting from transportation of radioactive materials and the costs and benefits of the alternatives available for reducing or avoiding the adverse environmental effects, the staff concludes:

   -Radiation exposure of individuals from normal transportation is within recommended limits for members of the general public. A few individual transport workers whose radiation exposures exceed the limits established for members of the general public should be, and in most cases are, monitored and otherwise treated as radiation workers.

-The average radiation exposure of the population at risk from normal transportation is a very small fraction of the limits recommended for members of the general public from all sources of radiation other than natural and medical sources, and is a small fraction of natural background exposure.

-The radiological risk from accidents in transportation is small, amounting to about one-thousandth of the normal transportation risk on an annual basis.

-To maintain the environmental impact of the transportation of radioactive materials at its present low level, effective means must continue to be provided to protect shipments of important quantities of radioactive material from theft and sabotage. Air transport provides the potential for one of a limited number of those effective means of protection. While further studies are being completed to determine the cost and effectiveness of alternate systems to protect radioactive material from theft and sabotage, the option of the air mode for such transportation should not be precluded.

-Alternatives should be further considered as to their cost-effectiveness in reducing radiation exposures from transportation to levels that are as low as reasonably achievable, taking into account social and economic considerations.

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DETAILED SUMMARY

Introduction

This document is an assessement of the environmental impact from transportation of shipments of radioactive material into, through, and out of the United States. It is intended to serve as background material for a review by the United States Nuclear Regulatory Commission of regulations dealing with transportation of radioactive materials. The impetus for such a review results not only from a general need to examine regulations to insure their continuing consistency with the goals of minimum radiological impact, but also from a need to respond to current national discussions of safety and security aspects of nuclear fuel cycle materials.

The report consists of seven chapters and appropriate appendices. The structure of the report and its content are indicated in the following outline of its chapters:

I. Introduction - The background of the study, the uses of radioactive materials, and shipping activities in various major segments of the nuclear industry are discussed.

II. The Regulations Governing Radioactive Materials Transport - The regulations are reviewed together with supporting information indicating the intent and basis for many regulations.

III. Radiological Effects - Since the primary impact of radioactive material transport is radiological, the mechanism for radiological impact, the appropriate protection guidelines, and the health effects model used in this assessment are discussed.

IV. Transport Impacts Under Normal Conditions - The environmental impacts that result from normal transportation, both radiological and nonradiological, are assessed in terms of a standard shipments model designed to represent current transport conditions.

V. Effect of Transport Under Accident Conditions - The radiological and nonradiological impacts that result from accidents involving vehicles carrying radioactive material shipments are discussed.

VI. Alternative Changes in radiological impact resulting from transport mode shifts, operational constraints, form and quantity limits, and packaging standards changes are assessed, and cost-benefit trade-offs are discussed.

VII. Security and Safeguards - The need for security of certain radioactive material shipments is discussed, together with the relative security of various modes of transport.

Description of the Environmental Impact of Existing Activities

The environmental impact of radioactive material transport is best described in three distinct parts: the radiological impact from normal transport, the risk of radiological effects from accidents involving vehicles carrying radioactive material shipments, and all nonradiological impacts.

Radiological impacts in normal transport occur continuously as a result of radiation emitted from packages both aboard vehicles in transport and in associated storage. The radiation exposure of selected populations such as

crew, passengers, flight attendants, and bystanders is calculated in the report using a computer model which considers radiation exposure rates, shipment information, traffic data, and mode splits for the principal radionuclides shipped. From the computer model, using the best input data available on current shipping practices, it was estimated that the total annual population exposure resulting from normal transport is about 9600 person-rem. The largest fraction of this population exposure (some 70%) results from the shipment of medical-use radionuclides, while the remaining portion results from industrial shipments (about 20%) and nuclear fuel cycle shipments (10%). Shipments by truck produce the largest population exposure, resulting from relatively long exposure times at low radiation levels of large numbers of people surrounding transport links.

The individual radiation exposures are generally at low radiation levels, and take on the character of a slight increase in background radiation. The analysis shows that radiation exposure from normal transportation, averaged over the number of persons exposed, amounts to one-half millirem per year, compared to the average natural background exposure of 100 millirem per year. This would result in a statistical increase of one latent cancer fatality per year in the United States from normal transportation of radioactive material, as compared to the existing rate of 300,000 cancer fatalities per year from all other causes.

Abnormal transport occurrences such as loss, mislabeling and crushing of packages were considered to have a minor impact compared to the total radiological impact from normal transport. A population exposure of 100

person-rem per year is an upper limit for this component of exposure; actual exposures are expected to be lower.

In the accident case, risk to the population from accidents involving vehicles carrying radioactive materials was estimated in terms of the number of latent cancer fatalities and the probability that early deaths will result from infrequent accidents involving radioactive material shipments. The analysis results in estimates of average societal risks of 5.6×10^{-4} latent cancer fatalities per year, and 7.4×10^{-8} early fatalities per year, as compared to 160 fatalities per year (in 1969) by lightning. These risks arise principally as a result of the very unlikely event of a major release of plutonium associated with the nuclear fuel cycle. The consequences of such an accident, although very unlikely, could be severe for a few individuals. Occurrence in a densely populated area (4,000 persons/km^2) could produce one fatality within 365 days and about sixteen exposures sufficient to produce death from cardiopulmonary insufficiency in some cases. The latent cancer fatalities associated with this major release are estimated at twenty per year over a thirty year period. The probability of such an occurrence is estimated to be 10^{-9} per year in 1974.

Nonradiological impacts such as area denial and the use of resources resulting from shipments of radioactive material were found to be negligible. Nonradiological impacts on safety were estimated to be two injuries per year and one fatality each four years from accidents involving vehicles used for the sole-use transport of nuclear materials.

To maintain the environmental impact of the transportation of radioactive material at its present low level, effective means must continue to be provided to protect shipments of important quantities of radioactive material from theft and sabotage. For long distance shipments, air transportation offers security advantages over surface modes. Air transport provides the potential for one of a limited number of effective means of protection. Rail may be an attractive mode for the shipment of nuclear reactor spent fuel, but, in general, more secure systems are available at less cost for other types of shipments.

Relationship of Proposed Activities to Other Activities by Government Entities

Regulation of radioactive material shipping is achieved by the NRC and the Department of Transportation in conjunction with cooperating state agencies. The interaction of these agencies is governed by either an agreement or a Memorandum of Understanding which defines their individual responsibilities.

Probable Impact of Proposed Actions on the Environment

Any actions produced as a result of this environmental assessment will be proposed in a future action and will be considered separately with that action.

Alternatives to Existing Activities

Alternatives to the existing activities in the radioactive material shipping industry are discussed in Chapter VI. Mode shifts, operational constraints, and package standards revisions were found to produce only small changes in the population exposure associated with normal transportation. Although large percentage decreases in the existing risk from transportation accidents

resulted from these alternatives, the results are mitigated by the following considerations:

a. Because the existing risk from transportation accidents is a small percentage of the risk from normal transportation, large decreases in accident risk result in insignificiant changes in the total (accident plus normal) risk; and

b. Because the existing risk from transportation accidents is so small, large percentage decreases are actually small decreases in terms of absolute effects (e.g. reduction in numbers of deaths or illnesses).

Where significant costs are associated with small absolute decreases in risk, better alternatives should be sought.

Changes in physical form to minimize the consequences of an accident involving plutonium were found to reduce the risk from such an accident. A factor of twenty decrease in accident risk and consequences seems attainable by this technique for plutonium shipments. There is not sufficient information available at this time on the feasibility of this alternative to determine its associated costs.

Unavoidable Adverse Environmental Effects

The principal unavoidable environmental effect was found to be the population exposure resulting from normal transport of radioactive materials. Since the radiation emitted from a package cannot be reduced to zero by any finite quantity of shielding, the transport of radioactive materials will always result in some population exposure.

The unavoidable risk from accidents which have the potential for releasing radioactive material from packages will always be present.

The unavoidable nonradiological impacts resulting from transport of radioactive material in sole-use vehicles amounts to about two injuries and less than one fatality per year, mostly from accidents involving transportation to and from nuclear power plants. Other nonradiological impacts such as the use of vehicle fuel and other resources were found to be insignificant.

Short Term Use of the Environment Versus Long Term Positive Effects

The most obvious and important short term effect is the radiation population exposure from normal transport, which statistically amounts to one latent cancer fatality per year. An additional short term effect is the small annual risk of accident exposure resulting from a very small probability of a transportation accident with serious consequences.

Balanced against these risks are long term positive results from the shipment of radioactive materials such as in:

a. National Health - The use of radiopharmaceuticals in the diagnosis and treatment of illnesses provides a benefit in lives saved which can be offset directly against the statistical loss of life resulting from population exposure in transport of the materials.

b. Oil Exploration - The use of radioactive material in well logging and flow tracing provides technology for intelligent exploitation of our oil resources, and aids in optimizing the use of this valuable national energy resource.

c. Quality Control - The use of radionuclides for gauging the thicknessess of metal and paper, measuring product density, and locating levels of contents in small packages and in large holding tanks provides a capability to minimize waste of resources and optimize quality in finished goods.

d. Electricity Generation - The use of nuclear fuels in reactors allows production of electricity for society with much lower levels of gaseous and solid pollutants to the environment than is possible by more conventional methods of generating electricity.

Irreversible Commitment of Resources

The only irreversible commitment of resources determined in this assessment was that resulting from use of fuels to operate the transportation network. To the extent that the resources are committed to the transportation of radioactive materials alone, the quantity of fuels used is an infinitesimal quantity, since transportation of radioactive material occurs incidentally to the movement of general goods in commerce. Only those portions of the fuel and other resources attributable to sole-use shipments are committed directly, and that activity is less than 10^{-5} of the nation's total transportation activity.

CHAPTER I

INTRODUCTION

A. Background and Purpose of this Environmental Statement

The purpose of this document is to assess the impact upon the environment from the transportation of radicactive materials, primarily by aircraft but also by alternative ground and water modes. The impact will be assessed by constructing a logic model to represent the various ways in which the transportation of radioactive materials can produce an environmental impact, by identifying the important paths in the logic model, and by evaluating the contributions of these various paths to the environmental impact. The conclusions are based upon a study begun in May 1975 by Sandia Laboratories under contract with the Nuclear Regulatory Commission (NRC).

NRC, organized under the Energy Reorganization Act of 1974, has the responsibility for assuring safety in the use of radioactive materials through licensing and regulation. Soon after its inception NRC stated that it intended to review those regulations and procedures originally set up by the Atomic Energy Commission (AEC) pertaining to the licensing and regulation of nuclear facilities and materials to determine what changes, if any, should be made. This environmental statement is, in part, an attempt to provide the technical data necessary for NRC to perform its reevaluation of the rules governing the transportation of radioactive materials. In addition, there has recently been some expression of concern by members of the Congress and the public about the safety and security of air shipments of plutonium and

other special nuclear materials through populated areas. The NRC authorization bill enacted into law on August 9, 1975, provides among other things:

> "The Nuclear Regulatory Commission shall not license any shipments by air transport of plutonium in any form, whether exports, imports or domestic shipments; Provided, however, That any plutonium in any form contained in a medical device designed for individual human application is not subject to this restriction. This restriction shall be in force until the Nuclear Regulatory Commission has certified to the Joint Committee on Atomic Energy of the Congress that a safe container has been developed and tested which will not rupture under crash and blast-testing equivalent to the crash and explosion of a high-flying aircraft."

The NRC announced[1] its initiation for a rule-making proceeding concerning the air transportation of radioactive materials, including packaging, and invited comments by the public on the existing regulations. Of particular interest are views and comments on:

1. Whether or not radioactive materials should continue to be transported by air.
2. The extent to which safety requirements should be based on accident probabilities, packaging, procedural controls, or combinations of these.
3. The relative risk of transport of radioactive materials by air compared to other modes of transport.
4. What improvements, if any, in the applicable regulations should be considered.

In order to determine the quantities and types of shipments of radioactive materials currently being transported, NRC contracted with Battelle Pacific Northwest Laboratories in Richland, Washington, to conduct a survey of the radioactive materials industry. Questionnaires were sent to about 2,300 of the approximately 18,000 licensees requesting data on the numbers and safety characteristics (e.g. quantity and external radiation level per package) of radioactive materials shipments. Detailed questionnaires were mailed to special nuclear material (SNM) licensees who shipped 1 gram or more of SNM between March 1, 1974 and February 28, 1975, and to approximately 150 "major shippers," i.e. licensees who are known to ship large numbers of packages or large quantities. Questionnaires requesting summary information only were sent to a sampling of the licensees selected from lists supplied by NRC and by the agreement states. Unfortunately, the results from these questionnaires were not received in time to be processed into a form useful to this draft assessment, but are expected to become available in time for use in the final version of this environmental statement. The shipment information used for this assessment was obtained from personal interviews, from an earlier shipper's survey,[6] and from other risk assessments.[7,8,9,10]

Section B of this chapter is an overview of the current industrial and medical uses of radioisotopes and their respective transportation requirements. The general scope of this environmental impact assessment is outlined in Section C. Section D contains a general discussion of the approach taken in the impact assessment. Finally, Section E contains an outline of the contents of each of the remaining chapters.

B. An Overview of Radioisotope Uses

Much of the information presented in this section was obtained from interviews with persons who either manufacture

radioactive sources and materials for industrial or medical use or who use radioactive materials in their work. All are dependent upon the transportation of radioisotopes to some extent.

Certain non-fissile radioisotopes are finding extensive applications in the radiopharmaceutical industry, in well-logging, in industrial radiography, as large-curie tele-theraphy and irradiator sources, and in the manufacture of certain types of gauges. Fissile materials, such as uranium-235, are used as fuel; others like plutonium-239 are produced in nuclear reactors. Together with relatively small amounts used in research these constitute the primary applications of radioisotopes. An estimated 600,000 packages of radioactive material are shipped annually by common carriers in the United States,[2] the greatest percentage of these are radiopharmaceuticals.

1. Radiopharmaceutical Industry - Most radiopharmaceuticals are used to diagnose diseases or locate tumors in various organs of the human body. The most commonly used isotopes are Tc^{99m} and I^{131}. Usually, the patient is given an injection of an isotope in the appropriate chemical form to localize it in the desired organ or system, and an imaging device is used to collect the emitted gamma rays and form an image of the organ containing the isotope. The techniques of nuclear medicine are practiced in about 3,300 hospitals in 1,500 cities in the United States.[3] Radiopharmaceuticals are also used therapeutically to treat malignancies. New applications for radiopharmaceuticals are being found, and the number of packages shipped is growing at the rate of 10 percent per year.[2]

Isotopes with short half-lives are used to make radiopharmaceuticals for diagnostic use, since they can be administered to the patient in larger doses than long half-life isotopes and, thus, produce more intense and better resolved images. The half-life of Tc^{99m}, probably the most prevalent isotope in radioactive diagnostics, is so short (6 hours) that it is supplied as Tc^{99m} or in the form of a Mo^{99} - Tc^{99m} "generator" in which the Tc^{99m} is produced continually by beta decay of Mo^{99}, which has a half life of about 66 hours. A saline solution is passed through an alumina column on which is adsorbed the parent molybdenum and daughter technetium. The Tc^{99m} is eluted by the saline to be injected into a patient for diagnostic purposes leaving the Mo^{99} source in the column to produce more Tc^{99m} for later use.

Most radiopharmaceuticals are produced in New Brunswick, St. Louis, Boston, Chicago, and San Francisco. Because of their short half-lives, they are usually flown to their destination on regularly scheduled passenger flights, although one large manufacturer now ships more than 50 percent of his packages by courier service fixed-bed trucks. Approximately 40 percent of his shipments go by passenger aircraft. Radiopharmaceutical packages shipped to hospitals or nuclear pharmacies contain at most a few curies and usually much less.

The packaging usually consists of several cardboard boxes, one inside another, with a lead-shielded "pig" inside the innermost box. The radiopharmaceutical, usually a liquid, is contained in a serum vial inside the pig. The vial is surrounded by absorbent material to contain the liquid in case the vial breaks.

The radioactive molybdenum in the Mo^{99} - Tc^{99m} generator package is contained in a glass or plastic column located inside a pig. The saline solution is shipped in the same package. Because the Mo^{99} - Tc^{99m} generators last about a week and because of the way physicians practicing nuclear medicine schedule their patients, the hospitals and pharmacies like to receive a fresh generator on Monday mornings. Thus, significantly more radiopharmaceutical shipments tend to occur over the weekend than during the week. Radiopharmaceutical packages are frequently picked up at the airport and delivered to the hospital by taxi, personal automobile, or courier service. In some cases, a freight forwarder is used.

In addition to supplying their customers, the radiopharmaceutical companies receive the raw materials from which they produce the pharmaceuticals. These come originally from reactors or cyclotrons. The raw materials are shipped in large casks approved for thousands of curies. Some companies have plants at more than one location and require transport of large curie quantities of materials between locations. These shipments are often made by all cargo aircraft.

2. <u>The Well-Logging Industry</u> - Well-logging firms use radioisotopes in their down-hole measurements to assess a well's capability for secondary and tertiary recovery. In a typical logging operation a neutron source and a gamma source are placed in an instrumentation package and lowered by means of a cable to the bottom of the bore hole. The package is then withdrawn slowly while the instrumentation detects the neutrons and gamma-rays backscattered from the surrounding strata,

and the detected signals are displayed on a chart recorder. The results yield information about the properties of rock formations as a function of depth.

Typically, an americium-241-beryllium neutron source of a few tens of curies and a cesium-137 gamma-ray source of several curies are used. These sources qualify as special form[4] since they are enclosed inside two small stainless steel cylinders, one inside the other, with welded end caps. The sources are fabricated in a hot cell by a service company often in the same locale as the well-logging firm. The service company purchases the radioisotopes from a company having access to a production reactor. The well-logging firms have to transport the sources to remote well sites and often to off-shore locations. They carry out logging operations both in the USA and in foreign countries including, for example, Canada, England (North Sea), Germany, Brazil, Venezuela, and Iran. Exports of sources to foreign countries as well as long distance shipments within the USA (e.g. to Alaska) are sent by cargo aircraft. Prior to the embargo on radioactive and other hazardous materials by the Air Line Pilots' Association (ALPA) early in 1975 and the Federal Aviation Administration (FAA) rule change implementing provisions of The Transportation Safety Act of 1974 which prohibit all radioactive materials shipments on passenger aircraft other than those intended for research or medical use, most of these sources were shipped by passenger aircraft. Deliveries of sources to sites within approximately a 1000 mile radius of the logging firm are generally made by truck, while deliveries to off-shore well locations frequently go by helicopter. Some logging firms and some oil

companies do radioactive tracer work in which they inject a radioisotope, usually I^{131}, Kr^{85}, or tritiated water ($H_2^3 0$), into a well to monitor its flow properties. The liquids are typically shipped in a glass serum vial carefully packaged in a metal can containing enough absorbent material to absorb the liquid contents in case of breakage. The can is shipped inside a lead-shielded container.

3. The Radiography Industry - Radiography sources are made primarily from one of two isotopes, Ir^{192} or Co^{60}, both gamma-ray emitters. The gamma rays are used to examine the structural integrity of welded joints principally in large pipes and pressure vessels. The source is positioned at the end of a short flexible steel cable to facilitate handling in the radiography "camera." The gamma rays emitted by the source pass through the welded joint and expose a piece of photographic film. The voids show up as dark spots on the developed negative. The radioactive sources are enclosed by two small, welded, stainless steel capsules and are considered as special form.(4)

Only a few companies manufacture these sources, obtaining the raw materials from production reactors; but there are numerous radiographers who use them. Unlike the radiopharmaceutical industry, the radiography industry requires shipments of sizeable quantities of radioisotopes between manufacturer and user in both directions. A fresh source, typically 100 curies, is sent to a radiographer for use in his camera. When it has decayed to about 30 curies, it is returned to the manufacturer in exchange for a new source. The new source is returned in the same shielded container in which it is shipped and stored.

Some radiography cameras are used for field work, e.g. at pipeline installations, and require transportation from the field office to a remote site. The units are fairly portable and are usually transported by small truck or van. However, the majority of radiography is done at fabrication plants requiring no transport except to and from the supplier.

4. Large Curie Sources - Teletherapy sources containing large quantities of Co^{60} (up to 10,000 curies) are fabricated and shipped to cancer treatment centers both in the USA and abroad. Overseas exports are transported by ship, while domestic shipments go by truck or rail. Irradiator sources, usually Co^{60} or Cs^{137}, are used in large scale sterilization operations and contain hundreds of thousands of curies. These sources are returned to the manufacturer after decaying to about 30-50 percent of their initial strength. They are shipped in large casks which, in general, are too heavy to be transported economically by aircraft.

5. Radioactive Gauges - A number of gauges are manufactured which use radioisotopes. Some gauges are used to measure the density of a liquid flowing in a pipe. Other gauges determine the level of a liquid or solid material inside large storage containers. Some thickness measuring instruments use radioactive sources. Most of these devices use Cs^{137}, but a few use Co^{60} or Ra^{226}. The sources are usually special form in double-welded capsules; they may contain as many as a few curies, but more often are a few hundred millicuries. They are packaged in lead containers and are shipped by motor freight. Some are exported overseas by ship. The radioactive materials used to make the

sources are purchased from companies which obtain them from production reactors, often in quantities of 10 to 100 curies. Once these sources are installed, they are not moved until disposal.

6. The Nuclear Power Industry - Nuclear Reactors - All of the previously mentioned radioisotopes used for industrial and medical purposes are produced either in nuclear reactors or in cyclotrons. A nuclear reactor is a device in which fission energy is released. Fission reactions are highly exothermic, and the thermal energy released is utilized in power reactors to produce electricity.

Only three relatively stable nuclides are useful as fuel for nuclear reactors. These are uranium-233, uranium-235, and plutonium-239. All light-water power reactors use uranium which has been slightly enriched (less than 5%) in the U-235 isotope.

A general nuclear fuel cycle associated with the production of electrical energy from fission is shown schematically in Figure I-1. Higher grade ores containing 2 to 5 percent uranium are concentrated to about 75% U_3O_8 near the source of the ore and shipped to a conversion plant. The uranium in the U_3O_8 consists mainly of the isotope U-238; 0.71% is U-235. At the conversion plant the U_3O_8 is converted to UF_6. The UF_6 is shipped as a solid to a uranium enrichment plant where it is enriched in the fissionable isotope U-235. The enriched UF_6 is sent to a fuel fabrication facility where it is converted to UO_2 and pressed into pellets. The pellets are fabricated into fuel rod assemblies, and the completed fuel assemblies are sent to a light water reactor where they are used to generate electrical power.

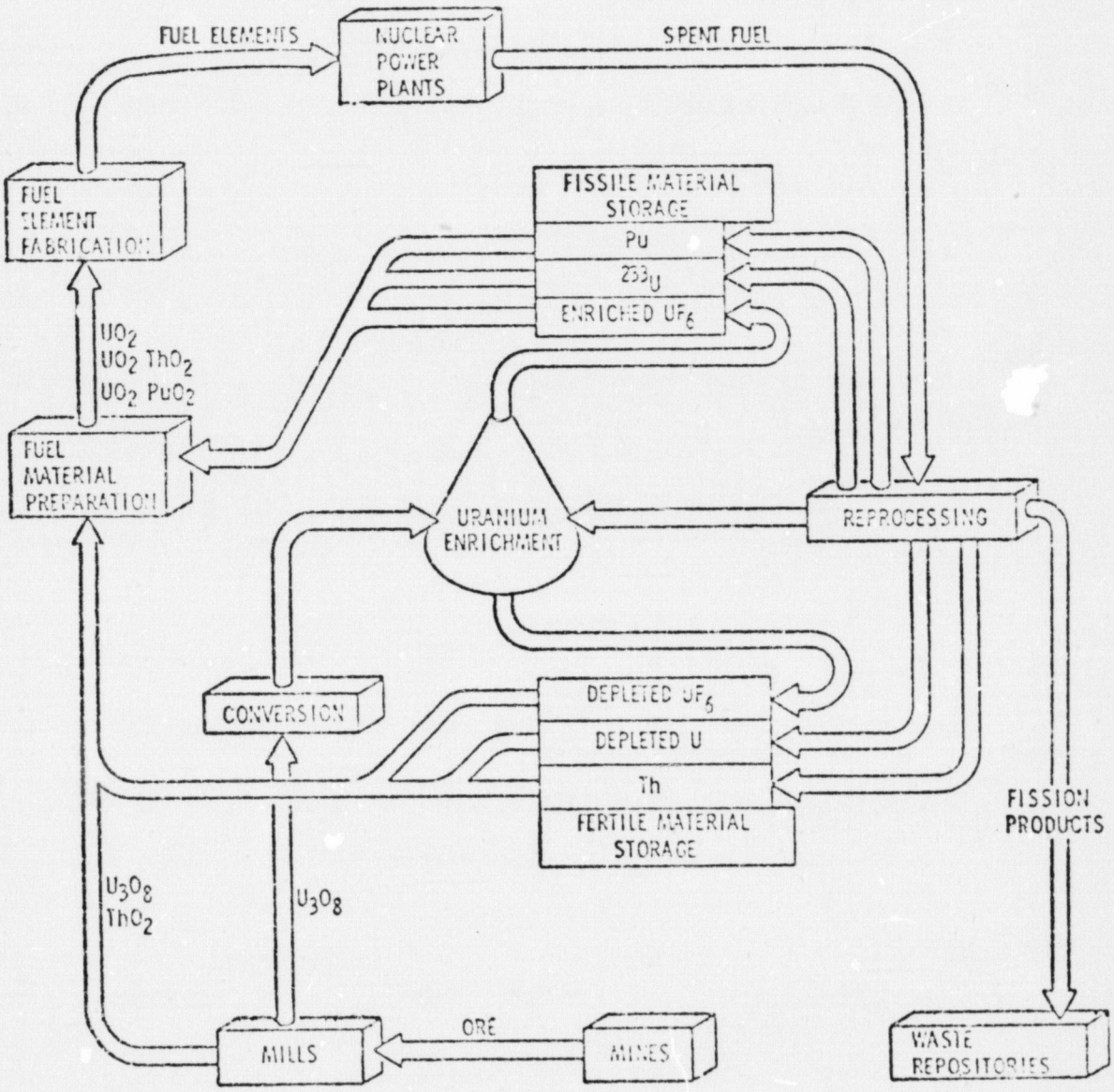

Figure I-1. Nuclear fuel cycle*

*Excerpted from Nuclear News

The U^{235} content of the fuel elements is reduced during operation until the elements have to be replaced. In addition, some of the U^{238} is converted into Pu^{239}. The reactor is periodically shut down to remove the spent fuel elements, which are sent to a reprocessing plant. At the reprocessing plant the spent fuel is separated from the cladding and is processed in a bath of hot nitric acid. The uranium, plutonium and fission products are chemically separated.

The recovered uranium is sent back to the enrichment plant while the liquid plutonium nitrate is stored. The high-level waste products are currently being stored temporarily, awaiting the approval of a site for a permanent waste repository.

To reduce the demand for uranium and to utilize the plutonium produced in the reactors, an alternative procedure would involve mixing plutonium as an oxide with the UO_2 and "burning" the mixed oxide fuel in the reactor. An environmental impact assessment[5] for mixed oxide fuels is being prepared, but is not yet complete. There is currently no recycling of plutonium except for use in a few experimental reactors.

The high-temperature gas-cooled reactor (HTGR) uses highly enriched (93%) uranium and thorium as fuel. The fuel cycle for this process is shown in Figure I-2. Uranium ore is converted to UF_6, enriched to 93 percent, and converted to enriched UO_2. Thorium is extracted from monazite ore, a mixture of rare earth phosphates containing 1 to 5 percent ThO_2. The extraction and purification process is similar to that used for uranium. The UO_2 and ThO_2 are converted to carbides, coated with

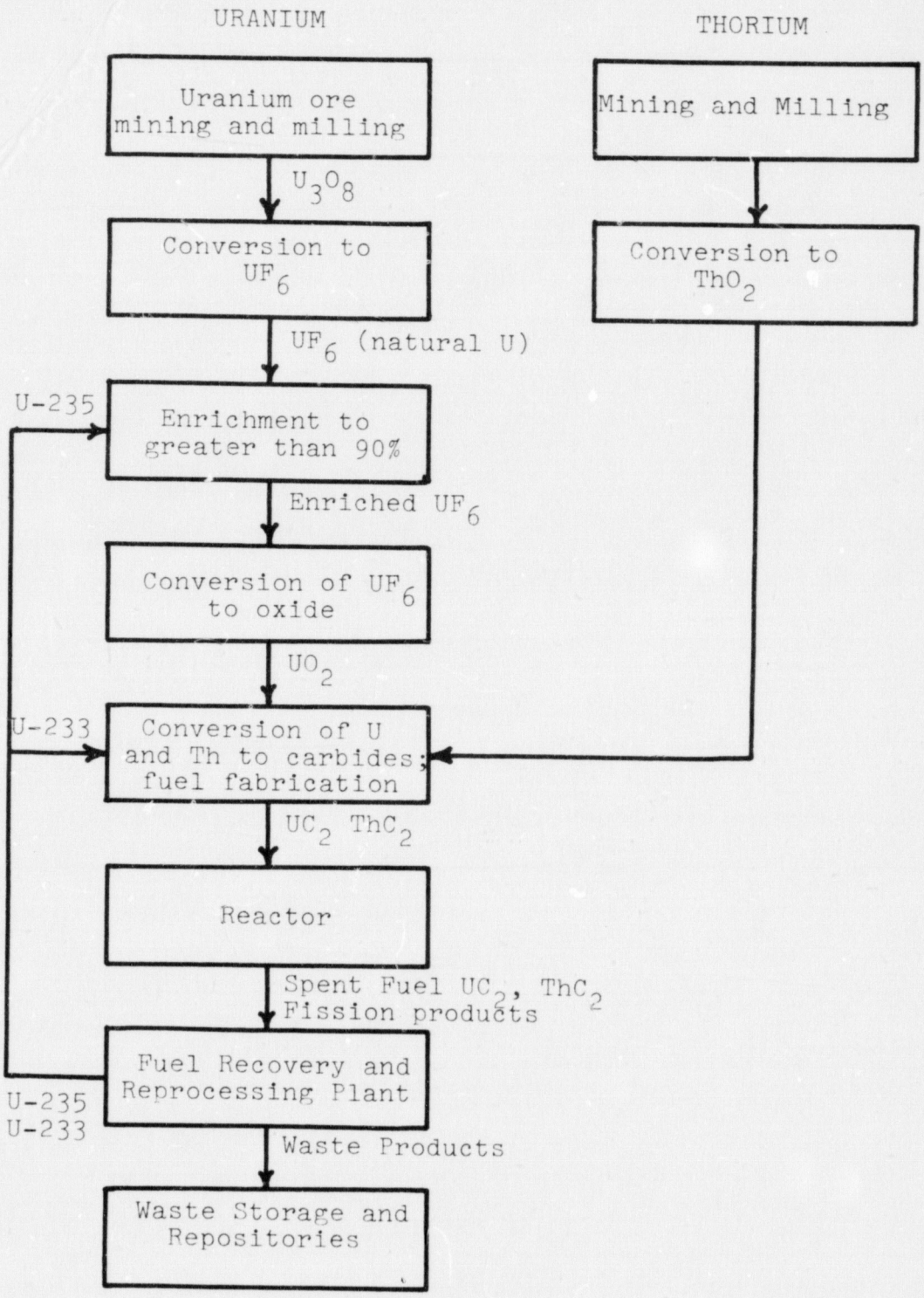

FIGURE I-2

High Temperature Gas Cooled Reactor (HTGR) Fuel Cycle

graphite, blended and formed into cylinders, and inserted into graphite blocks. The mixed fuel is then sent to the HTGR, which uses helium gas as a heat transfer medium. During operation of the reactor some of the thorium is converted to U^{233}. The spent fuel, after at least a 90-day cooling-off period at the reactor site, is sent to a reprocessing plant. The recovered U^{235}, now at a reduced enrichment level, is sent back to be enriched again up to 93 percent. The U^{233} is shipped to a conversion plant where it is converted to a carbide to be used as a replacement fuel for U^{235} in the reactor. There is currently only one licensed HTGR in the USA.

The Naval Nuclear Propulsion Program utilizes highly enriched uranium (> 90% U^{235}), but in a water-cooled reactor system. Like the other reactor types, the uranium is enriched as UF_6 by gaseous diffusion and converted to UO_2 for fabrication into fuel elements. Because there is very little U^{238} present in the fuel. only very small quantities of Pu are recovered during the reprocessing of the spent fuel. The recovered U^{235} is then re-enriched for reapplication to the fuel cycle.

Certain quantities of "special nuclear materials" (SNM), such as plutonium, U^{233}, and U^{235}, or uranium enriched in these isotcpes to a level of 20 percent or more require physical protection against theft and sabotage during transport because it is conceivable that they could be made into a nuclear explosive device. The regulations which prescribe the safeguards for these materials are given in 10 CFR 70 and 10 CFR 73 and will be discussed in the next chapter. The

types of shipments requiring safeguarding include most plutonium shipments and all shipments of highly enriched uranium such as those involved in the HTGR and Naval Reactor Programs. If and when plutonium recycling becomes a reality, there will be many more shipments requiring safeguarding. Although spent fuel contains sizeable quantities of plutonium the plutonium is not readily separable from the other radioactive material, and the activity of the irradiated fuel material is sufficiently high to exempt it from transportation safeguards requirements.

Much of the unirradiated SNM is transported in cargo aircraft and, prior to the DOT restrictions allowing only those radioactive materials intended for medical or research use, some went by passenger aircraft. The other principal mode of transport is truck.

7. Summary of Transportation Requirements - A summary of the principal transportation requirements of the radioactive materials industry in the USA is presented in Table I-1. The shipments listed and their modes of transport are thought to be representative of the radioisotope industry on July 1, 1975. Not shown are postal shipments of very small quantities of radioactive material. The principal and secondary transport modes are identified along with the packaging typically used.

C. Scope

Table I-1 also lists the principal types of radioisotope shipments within the industrial sector. The list includes shipments which take place within the nuclear power industry, shipments of pharmaceuticals, teletherapy sources, and industrial sources for well

TABLE I-1

RADIOISOTOPE SHIPMENTS SUMMARY - July 1, 1975

MATERIAL	ISOTOPE(s)	FROM	TO	PRIMARY MODE(s)	SECONDARY MODE(s)	PACKAGING
U-Ore	U^{238}, U^{235}	Mine	Mill	T_p	-	None
U_3O_8	"	Mill	Feed Preparation Plant	T, R	-	Steel Drums
Normal UF_6	"	Feed Preparation Plant	Enrichment Plant	T, R	-	Sealed Cylinders
Enriched UF_6*	"	Enrichment Plant	UO_2 Plant	T, R	-	Sealed Cylinders and protective packaging
Enriched UO_2*	"	UO_2 Plant	Fuel Fabricator	T	-	Drums with protective packaging
Fuel Elements*	"	Fuel Fabricator	Reactors	T, R	-	Special shipping containers
Low Level Wastes	Mixed Fission Products	Reactors	Commercial Burial Site	T	-	Drums and Shielded protective packaging
Irradiated Fuel	", U, Pu	Reactors	Reprocessor	T, R	-	Shielded Casks
P_uO_2*	Pu 238-242	Reprocessor	Fuel Fabricator	T, CA	T	Protective packages and special Pu shipping containers
Uranyl Nitrate	U^{238}, U^{235}	Reprocessor	Feed Preparation Plant	T, R	-	Tank trucks, Tank cars, and protective packaging
Fission Product Isotopes	Fission Products	Reprocessor	Government or Industry Users	T, R	-	Shielded Casks

*Indicates material which may require safeguarding per 10 CFR 73

TABLE I-1 (con't)

MATERIAL	ISOTOPE(s)	FROM	TO	PRIMARY MODE(s)	SECONDARY MODE(s)	PACKAGING
High Level Solid Waste	Mixed Fission Products	Reprocessor	Storage	T, R	-	Shielded Casks
Radio-pharmaceutical	Mo-Tc Gen	Supplier	Medical Facility	PA	T	Fiberboard boxes
"	Tc^{99m}	"	"	"	"	" "
"	I^{131}	"	"	"	"	" "
Radio-pharmaceutical Raw Material	I^{131}	Reactor, Cyclotron	Supplier	CA	T	Shielded Casks
"	Mo^{99}	"	"	"	"	" "
"	Mo^{99}	Supplier	Processor	CA	T	" "
Radiography Source	Co^{60}, Ir^{192}	Supplier	Distributor Radiographer	T	-	Special Radiography source shipping/storage containers
"	Co^{60}, Ir^{192}	Radiographer	Supplier	T	-	"
Radiography Source Raw Material	Co^{60}, Ir^{192}	Reactor	Supplier	T	-	Shielded Casks
Teletherapy Source	Co^{60}	Supplier	Medical Facility	T	-	Shielded Casks
"	Co^{60}	Medical Facility	Supplier	T	-	Shielded Casks
Irradiator Source	Co^{60}, Cs^{137}	Supplier	User	T, R	T	Shielded Casks
"	Co^{60}, Cs^{137}	User	Supplier	T, R	T	Shielded Casks

TABLE I-1 (con't)

MATERIAL	ISOTOPE(s)	FROM	TO	PRIMARY MODE(s)	SECONDARY MODE(s)	PACKAGING
Large Source Raw Material	Co^{60},Cs^{137}	Reactor	Supplier	T	-	Shielded Casks
Well-Logging Source	Cs^{137},Am^{241}	Supplier	Logging Firm	T	-	Special Logging Source Shipping Containers
Well-Logging Source	Cs^{137},Am^{241}	Logging Firm	Remote Site	T, CA	H	"
Well-Logging Source Raw Material	Cs^{137},Am^{241}	Reactor	Supplier	T, CA	-	Shielded Casks
Gauges	Cs^{137},Co^{60}	Supplier	User	T	-	Special Containers
Gauge Raw Material	Cs^{137},Co^{60}	Reactor	Manufacturer	T	-	Shielded Casks

Table of Abbreviations

T - Truck

R - Rail

CA - All-Cargo Aircraft

PA - Passenger Aircraft

H - Helicopter

logging, radiography, and gauging. The general types of shipments listed in this table are the subject of this impact assessment. Weapon shipments and all shipments in government-owned vehicles are considered to be outside the scope of this document. The shipments specified in Table I-1 do not list all possible transport modes for each shipment type, but rather show the modes being used on July 1, 1975.

D. Approach to the Problem - Industry Model

In order to quantitatively assess the environmental impact, a list of standard shipments was compiled from the general list in Table I-1, which is representative of shipments of radioactive materials as of July 1, 1975. This shipment list, used to model the industry, is shown in Table I-2. It is evident from a comparison of this table with Table I-1 that certain shipment types are not considered. The selection of standard shipments to represent the industry was made on the basis of:

1. The number of shipments of each type per year.[2,6]
2. The potential radiation hazard of the isotopes involved.
3. The results of previous radioactive materials transportation risk assessments.[7,8,9,10,11]
4. Information obtained from interviews with industry representatives.

The majority of packages of radioactive material shipped today contain radiopharmaceuticals. An estimated 600,000 packages of radioactive material were shipped in 1974 and were distributed as shown in Table I-3.[2] The 1985 projections were estimated using a fixed rate of growth suitable to the material.

TABLE I-2

STANDARD SHIPMENTS FOR THE NUCLEAR INDUSTRY

Shipment Class	Avg. Ci/Pkg	Avg. TI/Pkg	Total Packages/Year 1975	Total Packages/Year 1985	Transport Mode Split - % of Total: Pass. Air & Van	Cargo Air & Van	Truck	Rail
Tc^{99m}	0.28	0.1	1.14×10^5	2.96×10^5	100%	--	--	--
Iodine Small	0 012	0.8	1.91×10^5	4.95×10^5	52.5	37.5	10	--
Iodine Large	56.7	1.6	1.00×10^3	2.59×10^3	--	100	--	--
Mo^{99} Small	0.60	2.4	1.01×10^5	2.62×10^5	32.5	32.6	34.9	--
Mo^{99} Large	80	3.6	7.20×10^3	1.87×10^4	--	100	--	--
RAPH Small	0.042	0.5	1.33×10^5	3.45×10^5	52.5	37.5	10	--
RAPH Large	74	1.7	2.70×10^3	7.00×10^3	--	100	--	--
Ir^{192} Source	100	5.0	6.6×10^3	1.71×10^4	--	--	100	--
Ir^{192} Raw Material	5000	10.0	1.30×10^2	3.37×10^2	--	100	--	--
Spent Fuel SF Kr	2000 (Equiv.)	0	370	3.6×10^3	--	--	14.2	85.8
Spent Fuel SF I	2 (Equiv.)	0	370	3.6×10^3	--	--	14.2	85.8
Spent Fuel SF FP	800	100.0 (Equiv.)	370	3.6×10^3	--	--	14.2	85.8
PuO_2	3628	5.0	370	925	--	35	65	--

TABLE I-3

1974 RADIOACTIVE MATERIALS SHIPMENTS*[2]

Type of Material	Number of Pkg. Shipped in 1974	% of Total
Radiopharmaceuticals	500,000	83%
Medical Research	70,000	12
Research	24,000	4
Industrial	6,000	1
TOTAL	600,000	100%

*Excluding fuel cycle shipments.

The radiopharmaceutical shipments were categorized into four groups on the basis of a survey[6] of shipments made during one week in 1973.* According to the survey, three materials: molybdenum-99, technetium-99m, and iodine (including the isotopes I-123, I-125, and I-131) accounted for over 75 percent of the packages shipped. For this risk estimate, all other radiopharmaceuticals were lumped into one group called "RAPH". The 1973 survey results were tabulated according to the number of packages of each radionuclide shipped within a given quantity range. The quantity ranges were 1 mCi or less, greater than 1 to 100 mCi, greater than 0.1 to 1 Ci, greater than 1 to 3 Ci, greater than 3 to 20 Ci, greater than 20 to 1000 Ci, and greater than 1000 Ci. The total number of transport indices (TI) in each category were also listed for each isotope (see Chapter II, section D for the definition of TI). The iodine, molybdenum, and RAPH shipments were further grouped into large and small quantity shipments, with the dividing line between the two in the 1-3 Ci range. There were so few large Tc^{99m} shipments that they were all lumped into one group.

*This data is expected to be updated by a more extensive survey now in progress.

The follcwing example for small iodine shipments illustrates the methods used to determine the average number of curies per package, the average TI per package, and the number of packages shipped per year. The survey indicated that during one week there were 1020 packages in the less than 1mCi range, 1410 in the 1 to 100mCi range, and 45 in the 0.1 to 1 Ci range. The average number of curies per package in each range was estimated by taking the geometric mean of the extremes (except for less than 1mCi). The geometric mean was chosen to avoid attaching undue significance to the relatively few large quantity shipments. Thus, the average number of curies per package in the 0.1 to 1 Ci range was taken to be 0.32 Ci/pkg. Multiplying the total number of packages in each range by the average number of curies per package for that range, forming the sum over all ranges in the shipment class, and dividing by the total number of packages results in the average number of curies per package for the shipment class. For small iodine shipments, this is 29.52 Ci/2475 pkg., or 0.012 Ci/pkg. The average number of TI per package for each shipment class was determined in a similar way. It was determined from the survey that the number of small iodine packages constituted 34.66% of the total. It was estimated that the total number of radiopharmaceutical packages in 1975 would be 550.000, an increase of 10% over the 1974 estimate.[2] The number of small quantity iodine packages in 1975 was, therefore, estimated to be 0.3466 x 550,000 or 190,700. The transport mode splits for the various radiopharmaceutical shipment classes (small shipments only) are estimates based upon shipping information obtained from several radiopharmaceutical manufacturers.

According to Table I-3, about 1% of the number of radioactive material packages shipped annually contain industrial sources. The total number of industrial source packages estimated for 1975, assuming a 10% growth from the 1974 number is 6600. As a conservative estimate, these are all treated as 100 Ci Ir^{192} sources. The Ir^{192} raw material shipment class is intended to represent the raw material shipments from production reactors to industrial source fabricators. The total number of Ir^{192} raw material packages shipped, assuming 5000 Ci per package, was chosen to be consistent with the 6600 industrial 100 Ci sources shipped.

Most of the research and medical research isotopes shown in Table I-3 contain only small quantities. For the purposes of this impact assessment, they are included in the RAPH (small) category by an adjustment of the total number of curies for that category assuming an average of 0.1 mCi/pkg. The 1985 projections of the annual numbers of packages shipped are based upon an estimated growth rate of 10 percent per year for the radiopharmaceutical and industrial sources. The 1975 mode splits and shipment sizes are assumed.

The risks involved in transporting radioactive materials involved in the nuclear fuel cycle have been considered in previous studies, and the results of these studies are used in this report where applicable. The contribution of transportation of reactor fuel and the transportation of solid, packaged radioactive waste to the environmental impact of a typical LWR has been assessed.[7] A later document[8] discussed the environmental impact due to the other shipments involved in the UO_2-fueled LWR fuel cycle for a typical 1000 MWe reactor. Both documents

considered only those modes currently used, i.e., truck, rail, and barge; neither considered transport by aircraft. Another report [9] sponsored by the U. S. Environmental Protection Agency (EPA) presented the results of an assessment of the accident risks associated with the transportation of radioactive materials in the nuclear power industry from 1975 to 2020. The routine exposure due to shipments within the nuclear power industry was evaluated in an earlier EPA sponsored report.[10] A risk evaluation for truck shipments of plutonium oxide and plutonium nitrate has been made by Battelle Pacific Northwest Laboratories.[11]

A significant transportation risk from fuel cycle shipments occurs in the transport of irradiated (i.e., spent) fuel from a reactor to a reprocessing plant.[7] A similar risk occurs in the transport of high level radioactive wastes (HLRW).[8] Since there are currently no HLRW shipments and few, if any, are anticipated by 1985, they are not explicitly treated in the model. Spent fuel shipments are considered, and accidental releases are modeled by a method similar to that used in references (7) and (9). The annual numbers of spent fuel shipments for 1975 and for 1985 are estimated to be 370 and 3600, respectively.[12]

The total amount of plutonium shipped annually is estimated to be 2000 kg distributed over about 370 shipments, for an average of 5.4 kg per shipment. In order to compute the annual risk, one 5.4 kg package per shipment is considered. The transport mode split is estimated to be 35 percent by cargo aircraft, with van as the secondary mode at the shipping and receiving ends, and 65 percent by truck.[13] The projected number of shipments for 1985 is estimated to be 2.5 times the number for 1975,[13] assuming that NRC approves plutonium recycle. Although there have been no air shipments of plutonium since the August 9, 1975 ban, such shipments were taking place as of July 1, 1975, the date chosen for evaluation of the impact.

Method Used to Determine the Risk

The environmental impact assessment presented in this document makes use of a logic model which serves as a road map in the analysis of the various events or combinations of events which could produce an environmental impact. The model also illustrates the relationships between the events and their various effects. It has a tree-like structure with the undesired event, i.e., an impact upon the environment, at the top.

The top of the tree-structure is shown in Figure I-2. The first tier below the top lists three broad event classifications which catagorize the undesired event: the impact is produced during normal transport conditions, as a result of an accident, or as a result of diversion. The symbol beneath the rectangle identifying the undesired event is an "and" gate, indicating that the events in all of the three categories below contributes to the eventual environmental impact.

The normal case involves routine exposure to freight handlers, aircraft passengers and/or crew, truck drivers, bystanders along the route, etc., due to radiation emitted by the material and passing through the package outer surface or due to contamination of the package surface. There is no loss of containment in the normal case.

In the accident case one considers the additional hazard which could result from an accident involving a vehicle transporting one or more packages of radioactive material. Three possible hazardous conditions may arise in such an accident:

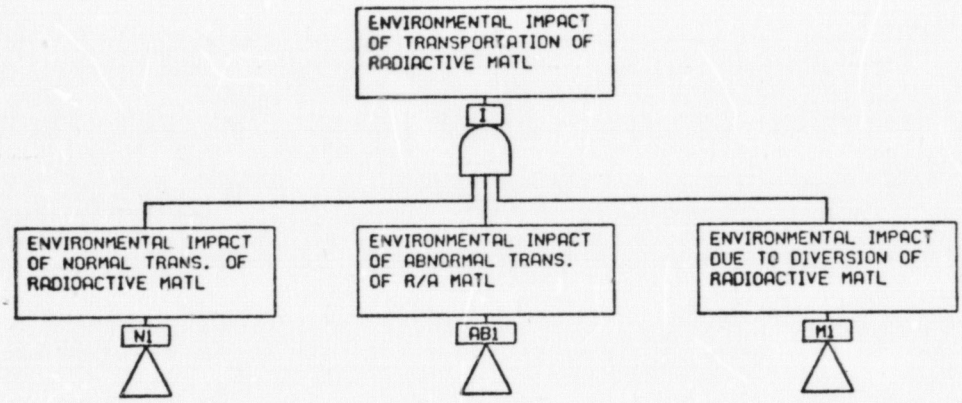

FIGURE I-3 Top of the Logic Model Tree Showing Initial Subdivision of Problem into Normal Case, Accident Case and Diversion Case.

a. a loss of shielding efficiency of the package,
b. a loss of containment of the radioactive material, and
c. accidental assembly of a critical mass in fissile material shipments.

The first condition could result in direct exposure of persons near the accident to radiation; the second could ultimately result in ingestion or inhalation of the radioactive material into a human body. The third case could result in neutron irradiation of persons in the vicinity of the accident at the time it occurs.

Diversion involves the sabotage or theft of a radioisotope shipment. Certain quantities of so called "special nuclear materials" such as plutonium and highly enriched uranium are possible targets for theft, since they might be used to make a nuclear device. Other radionuclides in large quantities may also become targets for sabotage.

Normal transport, accidents, and diversion are treated in separate chapters of this report, and each is analyzed according to the branch of the logic model which pertains to it. Quantitative estimates of the environmental impact are made for the normal and accident cases. The diversion case is not amenable to the quantitative analysis used in the normal and accident cases and is discussed from the point of view of the relative susceptibility to theft or sabotage of one transport mode with respect to another.

The environmental impact in the normal case is evaluated in terms of the expected annual population dose, expressed in person-rem, which results from the transport of radioactive materials, assuming there is no loss of containment or decrease in shielding efficiency during transport and that the material is packaged and shipped in accordance with the federal regulations.

The population dose resulting from the transport of any given package is proportional to its "transport index" or "TI" (see Chapter II, Section D, for a definition of transport index). By following a given package from the time it is presented for transport until it arrives at its ultimate destination, estimates of the total population dose per TI shipped are made. The methods of computing the dose depend upon the transport mode. The multiplication of the population dose per TI shipped by the number of TI shipped per year results in the expected annual population dose for each mode, and their sum gives the total expected annual dose due to normal transport.

An expected annual population dose is also computed in the accident case. This dose is determined by the number of curies shipped rather than the number of TI shipped. The dose is isotope dependent, particularly in the case of ingestion or inhalation of the spilled contents, since different isotopes have different biological effects when taken internally.

A population dose due to accidents is computed for each shipment type listed in Table I-2 in terms of person-rem per curie (or per gram) released in three different population zones. The dose calculation utilizes a Gaussian plume dispersion model developed for an analysis of the hazard of Pu^{239} dispersal. The material which escapes is assumed to be aerosolized (as a worst case) in a cloud which is initially ten meters high. Using diffusion climatology conditions based upon meteorological data, the cloud dispersal is calculated, the dose received in three different population density zones is computed and the results are used in the computation of the annual population dose for each of the standard shipments of Table I-2.

The results of the risk calculations for accidents involving shipments of radioactive material are presented also in terms of the probability of N early fatalities per year for various values of N.

The consequences of postulated accidents involving certain large quantity shipments are also evaluated. The results are presented in terms of the maximum population dose in person-rem per accident along with the number of persons receiving greater than specific doses of interest.

The discussion of the diversion of strategic special nuclear material (SSNM) is a qualitative comparison of the relative advantages and disadvantages of one transport mode with respect to another in the area of safeguards. It is assumed that the SSNM shipments follow the federal safeguards requirements. All connecting links and transfers in a given shipment are considered as possible targets for theft or sabotage; e.g., in aircraft shipments, the associated ground transportation and transfers of the material are considered along with the main air transportation link. The safeguards chapter also addresses the relative costs of various safeguards systems along with their relative effectiveness.

E. The Contents of this Document

The following chapter, Chapter II, discusses the federal regulations which apply to the transport of radioactive materials and the safeguarding of SSNM. It is the transportation of radioactive materials under these regulations which is the subject of this report. Chapter III is a general discussion of the biological effects of radiation exposure, including a discussion of the health effects model used in this assessment. The case of normal transport of radioisotopes and the associated environmental impact is discussed in Chapter IV. In Chapter V the impact due to

accidents is discussed. Chapter VI includes a discussion of alternatives to present shipping practice, including transport mode shifts, and their effect upon the environmental impact. The diversion of SNM and the evaluation of the steps taken to avoid diversion are discussed in Chapter VII.

REFERENCES - CHAPTER 1

1. Federal Register, Vol. 40, No. 106, p. 23768, June 2, 1975.
2. J. Calvin Brantley and Atomic Industrial Forum, Inc., Remarks Presented at Conference on Transportation of Hazardous Materials in Air Commerce, October 2-3, 1974.
3. J. Calvin Brantley, "Industry's Role in Transportation of Radiopharmaceuticals," Society of Nuclear Medicine, Annual Meeting, June 12, 1974.
4. A special form material is one which is essentially non-dispersible in water or in a fire. See Chapter II for a complete definition.
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CHAPTER II

THE REGULATIONS GOVERNING RADIOACTIVE MATERIALS TRANSPORT

A. Introduction

The objective of this chapter is to summarize in a clear and concise manner the federal regulations pertaining to the transportation of radioactive materials. Since it is only a digest of these regulations it is not possible for it to be complete in utmost detail. For detailed information the reader is referred to the appropriate sections in the Code of Federal Regulations (some of which are provided as Appendices to this document).

There are four basic safety requirements [1] which must be met when transporting radioactive materials:

1. adequate containment of the radioactive material,
2. adequate control of the radiation emitted by the material,
3. safe dissipation of heat generated in the process of absorbing the radiation and,
4. prevention of nuclear criticality, i.e., the accumulation of enough fissile material in one location to result in a nuclear chain reaction.

The purpose of the regulations is to ensure that these requirements are met. In the subsequent sections of this chapter the regulations relating to each of these safety requirements are discussed.

NRC regulations provide the standards which must be met rather than attempting to specify how they are to be met. An

example of the application of this basic concept is the fact that the regulations do not prohibit the shipment of any specific radioisotope as long as the basic safety standards are met.

Section B follows this Introduction and is a discussion of the various regulatory agencies and the sources of their respective regulations. In Section C are discussed those regulations and standards designed to ensure the containment of the radioactive material during transport, including the classification of radioactive materials for shipment, Type A packaging standards, Type B packaging standards, packaging for large quantities, exempt items, exempt quantities, and low specific activity (LSA) materials. Section D discusses the standards for radiation controls during transport and the definition of the transport index. The special regulations applicable to fissile materials for criticality control are discussed in Section E. Section F outlines the responsibilities of a licensee who receives a shipment of radioactive material and discusses procedures for picking up, receiving, and opening packages. The labeling requirements for packages are covered in Section G. In Section H the responsibilities of the carrier, including vehicle placarding and stowage, are discussed. Section I covers the requirements for the reporting of incidents and decontamination procedures. Finally, in Section J the requirements for the safeguarding of special nuclear material in transit are discussed.

B. Regulatory Agencies

The transportation of radioactive materials within the United States is regulated by the Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT). International shipments in most cases are made consistent

with the standards of the International Atomic Energy Agency (IAEA), with the DOT serving as the USA "competent authority." Certain so-called "exempt" quantities may be shipped by mail and are regulated by the U.S. Postal Service. Shipments not in interstate or foreign commerce or in air transportation as defined in the Federal Aviation Act of 1958 are controlled by NRC and by various state agencies.

The Nuclear Regulatory Commission (NRC) was established by the Energy Reorganization Act of 1974, which went into effect on January 19, 1975. This act also created the Energy Research and Development Administration (ERDA) and abolished the Atomic Energy Commission (AEC). The licensing and related regulatory authority held by the AEC under the Atomic Energy Act of 1954, as amended, was transferred to the NRC.

Chapter 1 of Title 10 of the Code of Federal Regulations contains the rules and regulations of the NRC, including rules relating to the issuance of general and specific licenses for receiving, acquiring, owning, possessing, using, and transferring by-product material, source material, and special nuclear material. A transfer of a non-exempt quantity of radioactive materials can take place only between person who are licensed by either the NRC or by certain "agreement states," a term to be explained later in this section. The most important parts of Title 10, Chapter I which pertain to radioactive materials transport are Parts 20, 70, 71, and 73, which deal respectively with Standards for Protection against Radiation, Special Nuclear Material, Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions, and Physical

Protection of Plants and Materials. In referring to these and other regulations in the Code of Federal Regulations an abbreviated form will be used, e.g., "10 CFR 71.35(a)" meaning "Paragraph (a) of Section 71.35 of part 71 of Title 10 in the Code of Federal Regulations."

The AEC, through formal agreements with certain states, transferred to those states the regulatory authority over byproduct material, source material, and less-than-critical quantities of special nuclear material. These so-called "agreement states" are Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Oregon, South Carolina, Tennessee, Texas, and Washington. These states have adopted a uniform set of rules requiring an intrastate shipper of radioactive materials to conform to the DOT requirements for packaging, labeling, and marking.

The Department of Transportation (DOT), under the Department of Transportation Act of 1966, the Transportation of Explosives Act, the Dangerous Cargo Act, the Federal Aviation Act of 1958, and the Transportation Safety Act of 1974 has regulatory responsibility for safety in transportation. The branch of the DOT concerned specifically with safety in the transport of radioactive and other hazardous materials is the Office of Hazardous Materials Operations.

The DOT regulations governing carriage of radioactive materials by rail and by common, contract, or private carriers by public highway (e.g. truck) are found in 49 CFR 170-189. The DOT regulations regarding packaging of radioactive materials are consistent with the NRC regulations

in 49 CFR 174-177. The DOT regulations regarding packaging of radioactive materials are found in 49 CFR 173, 178. The DOT regulations governing the transport of radioactive materials by air are in 14 CFR 103. The U.S. Coast Guard regulations in 46 CFR 146 apply to the carriage of radioactive and other hazardous materials by barge or ship.

Certain "exempt" quantities of radioactive material may be shipped through the mail. The regulations of the U.S. Postal Service found in 39 CFR 123-125 pertain to such shipments. The criteria used to determine how much radioactive material can qualify as "exempt" are discussed later in this chapter.

In order to carry out their respective regulatory functions for the safe transport of radioactive materials with as little duplication of effort as possible, the ICC and the AEC (now NRC) signed a "memorandum of understanding" in 1966 which has been superseded by a revised memorandum of understanding between DOT and AEC signed on March 22, 1973. According to the memorandum the DOT regulations (49 CFR 170-189, 14 CFR 103, and 46 CFR 146) apply to shippers as they pertain to packaging, marking, labeling, and to carriers as they pertain to vehicle placarding, loading, storage, monitoring, and accident reporting. All packagings for shipment of fissile material, Type B, and large quantities of radioactive material require approval by the NRC. In case of a transportation accident, incident, or suspected leakage of a package of radioactive material discovered <u>while in transit</u>, the DOT investigates the occurrence and prepares an investigation report. If, however, an accident or incident occurs, or suspected

leakage is discovered other than during transit, the occurrence is investigated by the NRC. The DOT is recognized as the "national competent authority" with respect to the administrative requirements of the International Atomic Energy Agency (IAEA) for the safe transport of radioactive materials. The two agencies have agreed to cooperate via exchanges of information in the development and enforcement of the regulations.

C. Regulations Designed to Insure Adequate Containment

The regulations to be discussed in this section provide standards for packaging and define limits for the package contents. The terms "package" and "packaging" are defined in 10 CFR 71.4 as follows:

> (k) "Package" means packaging and its radioactive contents;
> (l) "Packaging" means one or more receptacles and wrappers and their contents excluding fissile material and other radioactive material, but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and for absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment.

In defining the packaging standards and the package content limits, the consequences of loss of containment must be considered. In the event that some of the radioactive contents escapes from the package, a potential hazard to transport workers and to the general public exists due both

to the external radiation emitted from the exposed radionuclide and to the often more serious problem of ingestion into the body particularly through inhalation. Since the radiotoxicity hazards of the radionuclides vary by eight orders of magnitude,[2] a realistic set of standards should take into account which isotope is being transported. For this reason each radioisotope is classified, for transport purposes, into one of seven transport groups, labeled by Roman numerals I through VII according to their relative toxicity and potential hazard. A list of the radionuclides and their respective transport groups is found in 10 CFR 71, Appendix C (Appendix D-1, this document), and in 49 CFR 173.390.

Radioisotope quantities in each transport group are classified in order of increasing quantity, as "exempt," "Type A," "Type B," and "large quantity." The reason for this classification will become apparent in the next section. The limits for these quantity groupings are shown in Table II-1.

Certain physical forms of a radioactive material of any of the seven transport groups are classified as "special form" and are subject to the quantity limits shown in Table II-1 under "Special Form." A special form material is essentially non-dispersible in water or in a fire. The complete definition is found in 10 CFR 71.4(o) (See Appendix D-1, this document) and in 49 CFR 173.389.

Any radioactive material which does not qualify as a special form material is considered "normal form" and is categorized according to its transport group. While a special form material could, in the event of a severe

TABLE II-1

QUANTITY LIMITS FOR THE SEVEN TRANSPORT GROUPS AND SPECIAL FORM

Transport Group	Exempt Quantity* (Curies)	Type A Quantity** (Curies)	Type B Quantity (Curies)**	Large Quantity** (Curies)
I	$\leq 10^{-5}$	$>10^{-5}$ to 10^{-3}	$>10^{-3}$ to 20	>20
II	$\leq 10^{-4}$	$>10^{-4}$ to 5×10^{-2}	$>5 \times 10^{-2}$ to 20	>20
III	$\leq 10^{-3}$	$>10^{-3}$ to 3	>3 to 200	>200
IV	$\leq 10^{-3}$	$>10^{-3}$ to 20	>20 to 200	>200
V	$\leq 10^{-3}$	$>10^{-3}$ to 20	>20 to 5000	>5000
VI	$\leq 10^{-3}$	$>10^{-3}$ to 10^{3}	$>10^{3}$ to 5×10^{4}	$>5 \times 10^{4}$
VII	≤25	>25 to 10^{3}	$>10^{3}$ to 5×10^{4}	$>5 \times 10^{4}$
Special Form	$\leq 10^{-3}$	$>10^{-3}$ to 20	>20 to 5×10^{3}	>5000

*49 CFR 173.391.
**10 CFR 71.4 and 49 CFR 173.389.

Note: The regulations actually prescribe only the upper limits for Exempt, Type A, and Type B quantities. The symbol $\leq$ means "less than or equal to," and > means "greater than."

accident, present an exposure hazard, it is apparent from its definition that the chance of any significant amount of the contents being released into the air, groundwater, etc. and being ingested by a human is extremely remote. Examples of special form materials are radiography sources and unirradiated reactor fuel rods.

1. Type A Package

In order to be qualified for transport, all packaging used to contain radioactive material must meet the general requirements of 49 CFR 173.393. These requirements state, among other things, that the packaging must be adequate to prevent loss or dispersal of the radioactive contents and maintain the radiation shielding properties for the normal conditions encountered during transport. The contents of 49 CFR 173.393 are given in Appendix D-2. Tests to simulate normal transport conditions are outlined in 49 CFR 173.398(b) and in 10 CFR 71, Appendix A (see Appendix D-1).

The seven transport groupings and the Type A quantity limits have their origin in the IAEA regulations. The Type A limits were determined essentially in the following way.[1] It was recognized that the chance of a rail accident of such severity as to cause complete loss of the package contents was very small. Experimental work had indicated that a release of 0.1 percent of the package contents would be a reasonable assumption for the vast majority of possible accidents. Furthermore, on the basis of general handling experience, it was assumed the actual intake of radioactive material into the body by a person coming into contact with air or surfaces contaminated by such a release was unlikely

to exeed 0.1 percent of the amount released from the package. Thus, it would be unlikely for any one person to ingest more than one-millionth of the actual package contents in the event of an accidental release. Therefore, the Type A package limits were established on the bases that neither:

a. an intake of 10^{-6} of the maximum allowed package contents would result in a radiation dose to any organ in the body exceeding internationally accepted limits, assuming a 50-year life expectancy after the intake; nor

b. the external radiation from the unshielded contents would exceed 1 rem/hour at 10 feet.

In 49 CFR 178 there are descriptions of various DOT approved containers for Type A packaging including carboys, fiberboard boxes, steel drums, etc., which may be used without specific regulatory approval. However, in a recent rule making,(3) the DOT eliminated the various "hardware oriented" specifications for the Type A package containers listed in 49 CFR 173.394 (special form) and 49 CFR 173.395 (normal form) and ruled that each Type A package presented for shipment must be certified according to the Type A "Specification 7A" design. The requirements for this design are specified in 49 CFR 178.350. Such certification requires a supporting safety analysis. The use of existing "Specification 55" (49 CFR 178.250) containers is also authorized for Type A shipments, but the construction of additional Specfication 55 containers after March 31, 1975 has been prohibited. Foreign-made packagings properly labeled as "Type A" are also acceptable by the DOT for use in domestic transport (cf., 49 CFR 173.394(a)(7) and 173.395(a)(8)).

2. Type [illegible] Large Quantity Packaging

Quantities of radioactive material greater than the Type A limits can be transported only in Type B packaging. Type B packaging is considerably more accident resistant than Type A because it is designed to tougher standards. In addition to meeting the standards for a Type A package, a Type B package must also be able to survive certain hypothetical accident conditions with essentially no loss of containment and limited loss of shielding capability. The NRC packaging standards are given in Subpart C of 10 CFR 71, and the tests to simulate accident conditions are found in 10 CFR 71, Appendix B. A Type B packaging design requires the approval of the NRC before it can be used for shipping radioactive material.

The Type B quantity limits are to a certain extent somewhat artificial in that the regulations permit shipments of quantities greater than these limits as "large quantity" shipments in Type B containers. Like the Type A limits, they have their origin in the IAEA regulations, but they were chosen primarily on the grounds that:

1. they appeared to cover a transport need that existed at the time, and
2. safe dissipation of heat was not expected to present a significant problem.(1)

The types of packaging acceptable to DOT for Type B quantities, listed in 49 CFR 173.394 and 49 CFR 173.395,

are summarized in Table II-2 which includes the HM-111 rule changes.[3] They differ for special form and for normal form material. Special form materials may be shipped in existing Specification 55 (49 CFR 178.250) metal encased shielded containers, Specification 6M (49 CFR 178.104) metal packagings, or any other Type B packaging approved by NRC per 10 CFR 71. In addition, containers meeting the requirements of Specification 7A (49 CFR 178.350) or an existing Specification 55 container can be equipped with a Specification 20WC (49 CFR 178.194) wooden outer protective jacket; or a Specification 2R (49 CFR 178.34) or an existing Specification 55 container can be jacketed with a Specification 21WC (49 CFR 178.195) wooden-steel protection overpack to meet the requirements for Type B shipments. A Specification 55 container, used without a protective overpack, is limited to a maximum of 300 curies.

Solid or gaseous normal form materials may be transported in a Specification 6M container, provided they will not decompose at temperatures up to 250° F. A Specification 2R or existing Specification 55 inner container used with a Specification 20 WC wooden outer protective jacket, or any other Type B packaging approved by NRC per 10 CFR 71, may be used to ship Type B quantities of radioactive material in normal form. If the material is in liquid form, then the requirements of 49 CFR 173.393(g) must also be met for the inner package. For either normal form or special form materials, any Type B packaging meeting the 1967 IAEA regulations for which a foreign competent authority certificate has been revalidated by the DOT may be used.

Certain types of sources, particularly irradiated reactor fuel elements, irradiator and teletherapy sources, and most plutonium shipments contain quantities of radioactive materials in excess of the Type B limits. Packaging

TABLE II-2

Type B Packaging Permitted by DOT
for Transport by 49 CFR 173.394 and 49 CFR 173.395

Special Form	Normal Form
1. Spec 55 (300 Ci Max.) (49 CFR 178.250)	1. Spec 6M (for solid or gas only which does not decompose up to 250° F).
2. Spec 6M (49 CFR 178.104)	2. NRC (AEC) approved per 10 CFR 71.
3. NRC (AEC) approved per 10 CFR 71.	3. Type B packaging meeting 1967 IAEA regulations for which foreign competent authority certificate has been revalidated by DOT.
4. Type B packaging meeting 1967 IAEA regulations for which foreign competent authority certificate has been revalidated by DOT.	4. Spec 20 WC jacket with snug-fitting inner Spec 2R or existing Spec 55 inner package. For liquid, 173.393(g) must also be met for the inner package.
5. Spec 20 WC (49 CFR 178.194) outer jacket with snug-fitting Spec 7A (49 CFR 178.350) or existing Spec 55 inner container.	
6. Spec 21 WC overpack with single inner Spec 2R (49 CFR 178.34) or existing Spec 55 inner package securely positioned and centered.	

for large sources is subject to the requirements for Type B packaging plus additional requirements related primarily to decay heat dissipation (49 CFR 173.393(e)). The DOT requirements in 49 CFR 173.395(c) for large quantities of normal form material are as follows:

> (c) Large quantities of radioactive materials in normal form must be packaged as follows:
> (1) Specification 6M (§178.104 of this chapter) metal packaging. Authorized only for solid or gaseous radioactive materials which will not decompose at temperatures up to 250°F. Radioactive thermal decay energy must not exceed 10 watts.
> (2) Any other Type B packaging for large quantities of radioactive materials which meets the pertinent requirements in the regulations of the U.S. Atomic Energy Commission (10 CFR 71) and is approved by the U.S. Atomic Energy Commission.
> (3) Any other Type B packaging which meets the pertinent requirements for large quantities of radioactive materials in the 1967 regulations of the International Atomic Energy Agency, and for which the foreign competent authority certificate has been revalidated by the Department.

The requirements for large quantities of special form material are found in 49 CFR 173.394(c), and are substantially the same as for normal form except that, for special form, provision is also made for the use of existing Specification 55 containers with a 20WC overpack:

> (4) Specifications 20WC (§178.194 of this subchapter) wooden outer protective jacket, with a single, snug-fitting specification 55 inner packaging. Only use of existing specification 55 container authorized; construction not authorized after March 31, 1975. Radioactive thermal decay energy must not exceed 100 watts.

3. Exempt Items and Exempt Quantities

Certain small quantities of radioactive materials are exempt from specification packaging, marking, and labeling requirements, and from the general packaging requirements

of 49 CFR 173.393 as are certain manufactured articles, such as clocks and electronic tubes, containing radioactive materials in a non-dispersible form. These exemptions are covered in 49 CFR 173.391, which is included in Appendix D-3 of this document. The exempt quantity limits and the maximum allowable radioactivity content for exempt manufactured articles for the seven transport groups and for special form are given in Table II-3. The exempt quantity limits are also given in Table II-1. These limits were chosen in such a way that the release of even 100 percent of the contents in an accident would still represent a very low potential hazard as a result of intake to the body.

4. Low Specific Activity Materials

To meet the need for safe, bulk transportation of radioactive ores and slag or residues in processing, the DOT regulations in 49 CFR 173.392 provide exemptions from the requirements of 49 CFR 173.393 (a) through (e) and (g) in the case of so-called "low specific activity" (LSA) materials. However, LSA materials must be packed in accordance with the requirements of 49 CFR 173.395 and must be marked and labeled as required in 49 CFR 173.401 and 173.402. The contents of 49 CFR 173.392 are given in Appendix D-4 of this document. LSA materials are defined in 10 CFR 71.4(g) (see Appendix D-1, this document) and include uranium and thorium ores, ore concentrates, materials not exceeding the specific activity limits in Table II-3, certain contaminated non-radioactive materials, certain solutions of tritium oxide, unirradiated natural or depleted uranium, and unirradiated natural thorium. In defining the activity limits for LSA materials, the IAEA introduced the concept that, from a radiotoxicity point of view, LSA materials should be "inherently safe"; i.e. it is inconceivable that, under any circumstances arising in transport, a person could ingest enough material to give rise to a significant radiation hazard.[1] Thus, for LSA materials, it is the

TABLE II-3

LIMITS FOR EXEMPT QUANTITIES, LSA MATERIALS, AND MANUFACTURED ARTICLES

Transport Group	Small or Exempt Quantity Limit (mCi) (a)	LSA Materials Limits (mCi/gm) (b)	Maximum Radioactivity Content for Manufactured Articles (Curies) (a)	
			Per Device	Per Package
I	.01	.0001	.0001	.001
II	.1	.005	.001	.05
III	1	0.3	.01	3
IV	1	0.3	.05	3
V	1		1	1
VI	1		1	1
VII	25000		25	200
Special Form	1		.05	20
U^{235} content	15 grams			

(a) 49 CFR 173.391 - exempt from specification packaging, marking, and labeling requirements and from the general packaging requirements of 49 CFR 173.393.

(b) 10 CFR 71.4 (g) and 49 CFR 173.392 - for material in which activity is uniformly distributed; exempt from 49 CFR 173.393 (a) through (e) and (g), but must be packed in accordance with the requirements of 49 CFR 173.395 and must be marked and labeled as required in 49 CFR 173.401 and 173.402.

limited activity of the material itself rather than the packaging which permits shipments to meet the basic safety requirements. Nevertheless, both NRC and DOT place packaging requirements on shipments of LSA materials which are not transported on sole-use vehicles.

D. Radiation Control - The Transport Index

The second safety requirement which must be met when transporting radioactive material is the provision for adequate control of the radiation emitted from the material. This radiation is only partially absorbed by the containment system; in many cases some would pass through the packaging and would expose freight handlers and others who come into close proximity with the package if additional shielding were not placed around the material. In order to meet the radiation control limits, the shipper must provide the necessary shielding to reduce the external radiation level to within the allowable limits. The regulations prescribe limits which are chosen to protect not only persons but also animals and film. In fact, the radiation control surface dose rate limit of 0.5 mrem/hour for packages requiring no control was chosen to prevent fogging of sensitive x-ray film which might be transported in close proximity to the package containing the radioactive material over a 24-hour period.

For purposes of radiation control, packages of radioactive material are placed in one of three categories. Packages designated as "Category I - White" (they display a white label) may be transported with no special handling or segregation from other packages and must be within the 0.5 mrem/hour surface dose rate limit. If a transport worker were to handle such packages close to his body for 30 minutes per week he would receive an average dose rate of 10 mrem/year, which is a factor of 10 less than the average dose rate (100 mrem/year) received by an individual from natural background radiation.[1] The regulations

(cf 49 CFR 173.393(c)) also prescribe a minimum package dimension of 10 cm (4 inches) so that a handler cannot put the package in his pocket. The 0.5 mrem/hour surface dose rate limit also applies to "exempt" packages.

Packages designated as "Category III - Yellow" can have a surface dose rate no greater than 200 mrem/hour and a dose rate at 3 ft from any external surface no greater than 10 mrem/hour, with the latter criterion controlling for larger packages. This limit was chosen to prevent fogging of undeveloped x-ray film during a 24-hour period with a 15-ft separation, 15 ft being chosen as the U.S. Railway Express Company's 1947 conventional separation distance between parcels containing radium and parcels containing undeveloped x-ray film. A package giving 10 mrem/hour at 1 meter produces 11.5 mrem in 24 hours at 15 ft.[1] The 200 mrem/hour surface dose rate limit was chosen on the basis that a transport worker carrying such packages held against his body for 30 minutes per day would not receive a dose exceeding 100 mrem/8-hour working day, considered as acceptable in 1947. The permissible dose rate for male adult workers has since been revised downward to 6 mrem/8-hour working day. Thus, the 200 mrem/hour surface dose rate limit is acceptable only if the handling time is such that individual doses do not exceed the currently accepted limit of 500 mrem/year.[4]

An intermediate package category, "Category II - Yellow" includes packages with a surface dose rate not exceeding 10 mrem/hour and a dose rate at 3 feet from any external surface not exceeding 0.5 mrem/hour. Such packages require special handling but do not present the potential hazard that a Category III package presents. If a highway or rail vehicle carries a Category III package, it must be placarded. A summary of the dose rate limits for each package category is given in Table II-4.

TABLE II-4

PACKAGE DOSE RATE LIMITS

Category	Maximum Allowed Dose Rate (mrem/hr)*	
	Package Surface	3 Ft from Surface (TI)
I - White	0.5	-
II - Yellow	10	0.5
III - Yellow	200	10

*49 CFR 173.393(i)

Since a number of packages of radioactive material are often loaded onto a single transport vehicle which may also carry passengers (e.g. a passenger aircraft), a simple system had to be devised to enable transport workers to quickly determine how many packages could be loaded and how to segregate them from passengers and film. For this purpose the "transport index" or "TI" was devised. For nonfissile materials, the transport index is defined as the highest radiation dose rate in mrem/hour at three feet from any accessible external surface of the package, with the number expressing it rounded up to the next highest tenth (cf 49 CFR 173.389(i)(1)). For example, if the highest measured dose rate at 3 feet were 2.61 mrem/hour, the transport index for that package would be 2.7. From Table II-4 it would appear that no package with a TI greater than 10 may be transported. However, the regulations (cf 49 CFR 173.393 (j)) do provide for transport of packages with dose rates exceeding those in Table II-4 in a transport vehicle (except aircraft) which has been consigned as sole use provided the following dose limits are not exceeded:

> (1) 1,000 millirem per hour at 3 feet from the external surface of the package (closed transport vehicle only);
> (2) 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only);
> (3) Ten millirem per hour at any point 2 meters (six feet) from the vertical planes projected by the outer lateral surface of the car or vehicle; or if the load is transported in an open transport vehicle, at any point 2 meters (six feet) from the vertical planes projected from the outer edges of the vehicle.
> (4) 2 millirem per hour in any normally occupied position in the car or vehicle, except that this provision does not apply to private motor carriers.

When more than one package of radioactive material is loaded onto a transport vehicle, a total transport index

for the shipment is obtained by summing the TI's for each individual package. The total TI for packages loaded onto a single transport vehicle may not exceed 50 (cf 49 CFR 177.842(a), 49 CFR 174.586(h), and 14 CFR 103.19(b)). There are two exceptions to this rule. One is for vehicles (other than aircraft) consigned for sole use (49 CFR 173.393(j). The other is for transport by ship; in this case a total of 200 TI is permitted with the packages placed in single groups each having a total TI not greater than 50, and each such group located at least 20 feet from any other group (46 CFR 146.19-35). At least two cargo airlines are presently operating under special DOT permit to carry 200 TI, but all other aircraft are limited to 50. The regulations also provide tables of safe distances which must be maintained between stowed packages of radioactive material and persons or undeveloped film for various times of transport (cf 46 CFR 146.19-35 for ship, 14 CFR 103.23 for aircraft, 49 CFR 174.586(h) for rail freight, 49 CFR 177.842(b) for truck and other common, contract, or private carriers by public highway). It will be noticed from Table II-4 that these requirements apply only to Categories II - and III-Yellow packages. Category I packages are not assigned a transport index.

All packages are expected to retain their shielding effectiveness during normal transport conditions. The external dose rate, or TI, measured by the shipper and written on the package label must not increase during transport, e.g. due to faulty shielding. After being subjected to hypothetical accident conditions, any reduction of shielding caused by damage to a Type B package must not be sufficient to increase the external dose rate to more than 1000 mrem per hour at three feet from the external surface of the package (cf 10 CFR 71.36(a)(1).

E. Special Considerations for Fissile Material

The fourth basic safety requirement for transporting radioactive materials is the prevention of nuclear criticality for fissile materials. These are defined in 10 CFR 71.4(e) as uranium-233, uranium-235, plutonium-238, plutonium-239, and plutonium-241. The criticality standards for fissile material packages are found in 10 CFR 71.33 which states, in effect, that a package used for the shipment of fissile material is to be so designed and constructed and the contents so limited that it would be sub-critical if water were to leak into the package or if any liquid contents of the package were to leak out.

An assembly of a sufficient number of certain types of packages of fissile material, even though each package is subcritical, could conceiveably be grouped in such a way that the assembly becomes critical. The number of such packages which may be transported together depends upon the package design and contents. There are, however, some quantities, forms, or concentrations of fissile nuclides which cannot be made critical under any credible transport conditions. These are specified in 10 CFR 71.9 and are exempted from the special requirements for fissile material shipments. They include, for example, packages containing natural thorium and uranium or less than 15 grams of fissile material.

For shipments of fissile materials which do not qualify for exemption the regulations prescribe three package classes called Fissile Class I, II, and III. Fissile Class I packages are considered safe from nuclear

criticality by virtue of the package design and may therefore be transported in unlimited numbers and in any arrangement so long as the total radiation transport index limit is not exceeded. Such packaging must be so designed that it is a net absorber of neutrons in both normal and accident environments. The specific standards for Fissile Class I packages are given in 10 CFR 71.38.

Fissile Class II packages are those which, in a limited number, are considered to preclude criticality in any arrangement and for all foreseeable circumstances of transport. For purposes of nuclear criticality safety control, a special fissile transport index is assigned to such packages as follows:

$$\text{fissile TI} = 50/N$$

where N is the number of similar packages which may be transported together as determined under the limitations of 10 CFR 71.39(a). This transport index cannot be less than 0.1 nor more than 10. Thus, a shipment of N packages would not result in an aggregate transport index greater than 50. The actual transport index assigned to any fissile material package is always the greater of the fissile TI and the radiation TI determined from the radiation level at three feet from the package surface (cf 49 CFR 173.389 (i)). Aside from limiting the number of packages per shipment, Fissile Class II packages (like Class I) require no nuclear criticality safety control by the shipper.

Fissile Class III includes all packages of nonexempt fissile material not complying with the requirements of either Class I or Class II packages. Fissile Class III packages are those considered to preclude criticality under all foreseeable circumstances of transport by reason of special precautions or special administrative or operational controls imposed upon the transport of the consignment.[1] Special arrangements between the shipper and the carrier are required to provide nuclear criticality safety. The specific standards for such shipments are given in 10 CFR 71.40. International shipments of Fissile Class III packages require multilateral competent authority approval.[1]

Because of its toxicity, there are special requirements imposed on shipments of plutonium. There is currently a ban on shipments of plutonium in uncertified packagings by aircraft.[5] The requirements of 10 CFR 71.42 apply to plutonium shipments after June 17, 1978, and stipulate that plutonium in excess of 20 curies per package must be shipped as a solid and must be packaged in a separate inner container. Exempted from this requirement is solid plutonium in the form of reactor fuel elements, metal, and metal alloy.

The DOT packaging requirements for shipment of fissile materials are given in 49 CFR 173.396. This section specifies certain existing approved packagings for fissile materials and the authorized contents for each. Any new packaging design which is approved by NRC is automatically approved by DOT for fissile material shipments. Since fissile material quantities are usually given in grams or kilograms, one cannot use Table II-1 directly to determine into which quantity classification a given amount of a particular fissile isotope falls. The quantity limits in grams for Type A and Type B packages of some of the more important fissile materials are listed in Table II-5.

TABLE II-5

TYPE A AND TYPE B QUANTITY LIMITS IN GRAMS FOR CERTAIN FISSILE MATERIALS

Element	Specific Activity* (Ci/gm)	Transport Group	Maximum Content (grams)** Type A	Type B
Uranium (93% enriched in U-235)	7.0×10^{-5}	III	4.3×10^{4}	2.8×10^{6}
Uranium (40% enriched in U-235)	2.08×10^{-5}	III	1.44×10^{5}	9.62×10^{6}
Uranium (depleted - 0.2% U-235)	4.38×10^{-7}	III	6.85×10^{6}	4.57×10^{8}
Uranium (normal - .711% U-235)	6.85×10^{-7}	III	4.38×10^{6}	2.92×10^{8}
U-233	9.48×10^{-3}			
Pu-238	17.4	I	5.75×10^{-5}	0.119
Pu-239	6.14×10^{-2}	I	1.63×10^{-2}	32.6
Pu-240	0.226	I	4.42×10^{-3}	8.85
Pu-241 + daughters	112	I	8.93×10^{-6}	1.79×10^{-2}
Pu-242	3.9×10^{-3}	I	2.56×10^{-1}	5.11×10^{2}
Am-241 + Np-237	3.24	I	3.09×10^{-4}	0.617
Am-243 + daughters	1.85×10^{-1}	I	5.40×10^{-3}	1.08×10^{1}
Cf-252	536	I	1.55×10^{-6}	3.1×10^{-3}

*Los Alamos Scientific Laboratory Handbook of Radiation Monitoring - 1970 Edition

**Greater quantities must be shipped in packages approved for large quantities.

These were calculated from the data from Table II-1 and the respective specific activities, taking into account the transport group assigned to each isotope. It is apparent from the table that a package containing, for example, only 35 grams of Pu-239 would be classified as a "large quantity", i.e. greater than the Type B limit, whereas a package containing 100 Kg of 40 percent enriched uranium would be classified as a Type A quantity.

F. Procedures to be Followed by the Receiver

The standards discussed so far have been applicable to the shipper of radioisotopes and pertain primarily to packaging of the material in such a way that the transport occurs safely. The NRC standards of 10 CFR 20.205 outline the procedures for picking up, receiving, and opening the packages and apply to the licensee who is to receive the package. This section of the regulations is included in this document as Appendix D-5. These standards point out the responsibility of the receiver to:

1. Make arrangements with the carrier to receive the package or to receive notification of the arrival of the package at the carrier's terminal (in which case he is to pick up the package expeditiously from the terminal).
2. Monitor the external surfaces of the package for radioactive contamination caused by possible leakage of the radioactive contents and monitor the radiation levels on and at three feet from the external package surfaces. This monitoring must be performed no later than three hours after receipt of the package if received during normal working hours, and in any case, within eighteen hours.

3. Notify, by telephone and telegraph, both the final delivering carrier and the appropriate NRC Inspection and Enforcement Regional Office if the monitoring reveals either:
   a. removable radioactive contamination in excess of 0.01 microcuries per 100 square centimeters of package surface,
   b. radiation levels on the external package surface in excess of 200 millirem per hour,
   c. radiation levels at three feet from an external package surface in excess of 10 millirem per hour.
4. Establish and maintain procedures for safely opening packages in which licensed material is received, to assure that those procedures are followed giving due consideration to special instructions for the type of package being opened. Exemption from the requirements for monitoring external surfaces for contamination are provided in 10 CFR 20.205(b) for special form materials and gases, Type A packages containing only radioactive material in other than liquid form, packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries, all packages containing only exempt quantities, and packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125.

G. Labeling of Packages

Each package containing greater than exempt quantities of radioactive material must be labeled on two opposite sides (cf 49 CFR 173.402(a)(10)) with one of three warning labels described in 49 CFR 173.416. The labeling requirements are given in 49 CFR 173.399, '173.401 and '173.402.

All three label types contain the distinctive trefoil symbol and either one, two, or three vertical stripes. The one-striped label has a white background and is placed on a Category I - White package. A label with a bright yellow upper half and a white lower half is marked with either two or three vertical stripes and indicates a significant radiation level outside the package. The two-stripe label is placed on a Category II - Yellow package and the three-stripe label on a Category III - Yellow package. The radioactive White - I label may not be used for Fissile Class II packages (cf 49 CFR 173.399(a)(1)). Each Fissile Class III package, each package containing a "large quantity" of radioactive material, and certain types of packages must bear a Radioactive - Yellow III label '49 CFR 173.399(a)(2)). The label must show the isotope contained in the package, the number of curies, and the transport index (except for the White - I label). In addition, each package weighing more than 50 Kg (110 pounds) must have its gross weight marked on the outside of the package (49 CFR 173.401(f)(1)). Type A or Type B packaging must be plainly marked with the words "Type A" or "Type B", respectively. Packages destined for export shipment must also be marked "USA" (49 CFR 173.401(f)(2)).

H. Requirements Pertaining to the Carrier - Vehicle Placarding and Stowage

The DOT imposes certain regulations upon the carrier for radioactive materials transport. These include vehicle placarding, examination of shipper certification papers and packages for proper marking and labeling, and proper loading and stowage of the packages aboard the transport vehicle. Appropriate placards must be displayed on the front and rear and on each side of rail or highway vehicles carrying packages bearing the Radioactive-Yellow-III label. The regulations regarding placarding are given in 49 CFR 174.541 and '177.823.

In addition to placarding his vehicle as required, the carrier has the responsibility of insuring that the articles offered for transport have been certified by the shipper to be properly classified, described, packaged, marked, labeled, and in proper condition for transportation. For normal form materials, the shipping papers must include the transport group or groups of the radionuclides, the names of the radionuclides in the material, and a description of their physical and chemical form. For all radioactive material the activity of the material in curies and the type of radioactive label applied must also be listed. In addition, for fissile materials, the fissile class must be given with an additional warning statement as described in 49 CFR 173.427.

For shipments by aircraft, the operator of the aircraft (e.g. an airline official) must inform the pilot in command of the name, classification, and location of the radioactive material on the aircraft per 14 CFR 103.25. In addition, for passenger-carrying aircraft there must be a clear and visible statement accompanying the shipment, signed or stamped by the shipper or his agent, stating that the shipment contains radioactive materials intended for use in, or incident to, research, or medical diagnosis and medical treatment (14 CFR 103.3(e)).

The carrier is also required to make sure that the maximum allowable TI is not exceeded and that the packages are not transported or stored in groups having a total TI greater than 50. He must also assure that such groups of yellow-labeled packages are separated from areas continually occupied by persons, from film, and from shipments of animals. Further, he must assure that a fissile Class III package is not transported on the same vehicle with other fissile

material and is segregated by at least 20 feet from other radioactive material packages in storage. The pertinent regulations are found in 49 CFR 174.586 and 177.842, 46 CFR 146.19-35, and 14 CFR 103.23(a).

Special requirements for stowage of packages of radioactive material bearing Radioactive-Yellow-II or Yellow-III labels aboard aircraft are given in 14 CFR 103.23. For an aircraft loaded with the maximum allowable radioactive package load of 50 TI, a minimum distance of 7 feet must be maintained between the package and a space continuously occupied by people. In practice radioactive packages are usually placed as far to the rear of the aft cargo hold as possible in a passenger aircraft.

I. Reporting of Incidents and Suspected Contamination

If death, injury, fire, breakage, spillage, or suspected radioactive contamination occur as a direct result of hazardous materials transportation the regulations (49 CFR 171.15) require immediate notification of the DOT, and the carrier must submit within 15 days of the date of discovery a "detailed hazardous materials incident report" (49 CFR 171.16). In addition, he must notify the shipper (49 CFR 174.588). The vehicles, buildings, areas, or equipment in which a spillage of radioactive materials has occurred may not be used again until the radiation dose rate at any accessible surface is less than 0.5 mrem/hr., and there is no significant removable surface contamination (49 CFR Part 174.588(c) (1)). These procedures are essentially the same for all modes (14 CFR 103.23(b); 49 CFR 177.861(a); and 46 CFR 146.02-35). The carrier can obtain technical assistance in radiation monitoring following an incident or accident by calling one of the ERDA or NRC Regional Offices for Radiological Assistance.

The level above which removable radioactive contamination is considered "significant" depends upon the contaminating nuclide and is specified in 49 CFR 173.397(a). This section also prescribes a method for assessing the surface contamination of a package. For radioactive material packages consigned for shipment on exclusive use vehicles (49 CFR 173.389(a)), the "significant" levels of surface contamination is 10 times as great as for packages transported on non-exclusive use vehicles (49 CFR 173.397(b)). Exclusive use transport vehicles must be surveyed with appropriate radiation detection instruments after each use and may not be returned to service until the radiation dose rate at any accessible surface is 0.5 millirem per hour or less, and there is no significant removable radioactive surface contamination (49 CFR 173.397(c)).

J. Requirements for Safeguarding of Certain Special Nuclear Material

Certain strategic quantities and types of special nuclear material (SNM) require physical protection both at fixed sites and during transit against theft and sabotage because of their potential use in a nuclear explosive device. The NRC standards for physical protection of materials while in transit are found in 10 CFR 73.30 - 10 CFR 73.36. They apply to any person licensed pursuant to the regulations in 10 CFR 70 who imports, exports, transports, delivers to a carrier for transport in a single shipment, or takes delivery of a single shipment free on board at the point where it is delivered to a carrier, any one of the following: (10 CFR 73.1(b)(2), (3)).

1. 5000 gm or more of U-235 contained in uranium enriched in the U-235 isotope to 20 percent or more

2. 2000 gm or more of U-233
3. 2000 gm or more of plutonium
4. Any combination of these materials in the amount of 5000 grams or more computed by the formula:

grams = (grams contained U-235)
+ 2.5 (grams U-233 + grams plutonium).

The standards also apply to air shipments of SNM in quantities exceeding:

1. 20 grams or 20 curies (whichever is less) of plutonium or uranium-233, or
2. 350 grams of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope).

Quantities and types of SNM which require safeguarding are referred to as "strategic special nuclear material," or "SSNM". A licensee is exempt from these requirements for shipments of (cf 10 CFR 73.6):

1. Uranium enriched to less than 20 percent in the U-235 isotope,
2. SNM which is not readily separable from other radioactive material and which has a total external radiation dose rate in excess of 100 rem per hour at a distance of three feet from any accessible surface without intervening shielding (e.g. irradiated fuel), and
3. SNM in a quantity not exceeding 350 grams of uranium-235, uranium-233, plutonium, or a combination thereof, possessed in any analytical research, quality control, metallurgical or electronic laboratory.

The general requirements for physical protection of SSNM while in transit are found in 10 CFR 73.30 (included in Appendix D-4 of this document) and are concerned with the following:

1. The necessity for the shipper to make prior arrangements with the carrier for physical protection of the SSNM, including exchange of hand-to-hand receipts at origin, destination, and transfer points.
2. The minimizing of transit time and avoidance of areas of natural disaster or civil disorder (does not apply to the air shipments described earlier).
3. The required use of tamper-indicating type seals and locking of containers for specified contents. No container weighing 500 pounds or less can be shipped in open trucks, railroad flat cars, or box cars and ships.
4. The use and qualifications of guards.
5. The outlining of procedures to be followed by the licensee.
6. The provision for approval of special procedures not found in the standards.

Specific standards for safeguarding shipments of SSNM by road are given in 10 CFR 73.31. The basic requirements of this paragraph are as follows:

1. No scheduled intermediate stops are allowed.
2. Vehicles used to transport SSNM are to be equipped with radiotelephones, and contact with the licensee or agent is to be made, in most cases, every two hours.
3. Two people are to accompany the shipment in the vehicle containing the shipment. In addition,

either an armed escort consisting of at least two guards in a separate vehicle shall accompany the shipment (in this case only one driver is required in the vehicle containing the SSNM for shipments lasting less than one hour) or a specially designed truck or trailer which reduces the vulnerability to diversion shall be used.

4. The vehicles are to be marked on top with identifying letters, to permit identification in daylight and clear weather at 1000 feet above ground level, and also on the sides and rear of the vehicle.

Standards for safeguarding shipments of SSNM by <u>air</u> are discussed in 10 CFR 73.32:

1. Shipments by passenger aircraft* of plutonium or uranium-233 in quantities exceeding 20 curies or 20 grams (whichever is less) or 350 grams of uranium-235 contained in uranium enriched to 20 percent or more in the U-235 isotope must be specifically approved by the NRC.
2. Transfers are to minimized.
3. Export shipments are to be escorted by an unarmed authorized individual from the last terminal in the United States until the shipment is unloaded at a foreign terminal.

The regulations of 10 CFR 73.33 provide that, for safeguarding shipments by <u>rail</u>, an escort by two guards is required (guards are, by definition, uniformed and armed - see 10 CFR 73.2(c)). They ride either in the shipment car or an escort car from which they can keep the shipment car under observation. Radiotelephone contact with the licensee or his agent is to be made at specific intervals.

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*Note that 14 CFR 103 prohibits these shipments unless the materials are intended for medical or research use, and Public Law 94-79 prohibits NRC approval of shipments by air in uncertified packages of any licensed plutonium other than that contained in specified medical devices.

The regulations for safeguarding shipments of SSNM by sea given in 10 CFR 73.34 provide that:

1. Shipments shall be made on vessels making minimum ports of call and with no scheduled transfers to other ships.
2. The shipment is to be placed in a secure compartment which is locked and sealed.
3. Export shipments shall be escorted by an unarmed authorized individual from the last port in the United States until the shipment is unloaded at a foreign port.
4. Ship-to-shore contact is to be made every 24 hours, and the information regarding position and status of the shipment is to be sent to the licensee or his agent who arranges for the protection of the shipment.

The necessary transfers of SSNM during a shipment must be monitored by a guard. These monitoring procedures are outlined in 10 CFR 73.35:

1. At a scheduled intermediate stop where the SSNM is not to be unloaded, the guard is to observe the opening of the cargo compartment, maintaining continuous visual surveillance of it until the vehicle departs. Then the guard must immediately notify the licensee or his agent of the latest status.
2. At points where SSNM transfers occur, the guard is to keep the shipment under continuous visual surveillance, observe the opening of the cargo compartment for an incoming vehicle, and assure that the shipment is complete by checking locks and/or seals. Continuous visual surveillance is also to be maintained when the shipment is in the terminal or in storage. Immediately after a

vehicle carrying SSNM has departed, the guard must notify the licensee or his agent of the latest status.

3. The guard is to report immediately to the carrier and the licensee who arranged for the protection of the SSNM any deviations or attempted interference.

Finally, 10 CFR 73.36 contains miscellaneous safeguarding requirements for licensees who ship, receive, export, or import SSNM. The basic features of these requirements are as follows:

1. If a licensee agrees to take delivery of an f.o.b. shipment of SSNM, the licensee, rather than the shipper, arranges for the protection of the shipment while it is in transit.
2. A licensee who imports SSNM must assure that the shipment is not diverted in transit between the first point of arrival in the United States and delivery to him.
3. The licensee who delivers SSNM to a carrier for transport must, at the time of departure of the shipment, notify the consignee of the methods of transportation, the names of the carriers, and the estimated arrival time. The licensee must also arrange to be notified by the consignee immediately of the arrival of the shipment.
4. The licensee who exports SSNM must comply with this regulation for transport to the first point outside the United States at which the shipment is removed from the vehicle.
5. A licensee who receives a shipment of SSNM is to notify the shipper immediately upon arrival of the shipment at its destination.
6. If a shipment of SSNM is lost or unaccounted for

after the estimated arrival time, the licensee who arranged for safeguarding the shipment shall immediately conduct a trace investigation and file a report with the NRC as specified in 10 CFR 73.71.

REFERENCES - CHAPTER II

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3. Docket No. HM-111, Federal Register, Volume 39, No. 252, December 31, 1974

4. International Commission on Radiological Protection, Recommendations, ICRP Publication 9, Pergammon Press, Oxford (1966).

5. Public Law 94-79 (S.1716).

CHAPTER III

RADIOLOGICAL EFFECTS

A. Radiation

Radioactive nuclides undergo spontaneous decay resulting in the emission of radiation. The unstable nucleus emits a characteristic particle or radiation and is thereby transformed into either a completely different nucleus or a more stable form of the same nucleus. The "daughter" nuclide which results from this emission may also be radioactive, depending on the relative stability achieved by the nucleus via radiation.[1] The most important radiations from a radiological viewpoint are charged particles, neutrons, and electromagnetic radiations.

Charged particles such as beta particles and alpha particles interact strongly with matter through Coulomb forces. These interactions rapidly diminish the energy of the charged particles and, therefore, limit their travel to small distances. A 5 MeV alpha particle, for example, will only travel 3.4 cm in air and .002 cm in biological-tissue.

Electromagnetic radiation, such as x rays and gamma rays, interact with matter and thereby lose energy through processes such as the photelectric effect, Compton scattering, and pair production. Since these processes are less likely than the Coulomb interactions characteristic of charged particles, the range of electromagnetic radiation is much greater than that of alpha or beta particles of comparable energy. One MeV gamma radiation will travel 11 cm in biological tissue before half of its initial photons are absorbed.

Neutrons are another form of penetrating radiation. Fast neutrons interact with matter primarily through scattering collisions with nuclei. For neutron energies near 1 MeV, one-half are absorbed after passage through 10 cm of bio-tissue. "Thermal," or low-energy neutrons have a higher probability for absorption by matter. They are captured by some nuclei, a process often accompanied by subsequent radiation.

B. Dose

Radiation exposure may be measured in terms of its ionizing effect or in terms of the energy absorbed per unit mass of exposed material.

Historically, radiation exposure for x and gamma radiation was measured in terms of "roentgens," where one roentgen equals the amount of radiation required to produce one electrostatic unit (esu) of charge from either part of an ion pair in 1 cm^3 of dry air. It can be shown that one roentgen is equivalent to energy deposition of 88 ergs in one gram of dry air.[2]

A modern and more useful method for quantifying radiation interaction is in terms of the energy absorbed per unit mass. This "radiation absorbed dose" (rad) equals 100 ergs/gm of absorbing material.

Biological effects due to radiation exposure have been found to depend on the distribution of the energy deposition in tissue as well as the magnitude of the energy absorbed. Therefore, the nature of the radiation is also very important in ascertaining relative biological effects. By convention, these relative biological effects are expressed by a quality factor (QF). These quality factors are summarized below:

Table III-1

Quality Factors for Various Radiations[3]

Radiation	QF
x ray, γ ray	1
beta	1
neutrons (fast)	5 - 11
neutrons (slow)	2 - 5
alpha	20

The equivalent biological effect for all types and energies of radiation can, therefore, be achieved by defining the unit of rem ("Roentgen equivalent man")[4] as

$$\text{rem} = \text{QF} \times \text{rad}$$

In this form, doses to a given body organ are additive, independent of the type of radiation.

Radiation from sources external to the body is usually only harmful to humans when in the form of neutrons, x rays, or gamma rays. Typically, alpha and beta particles are stopped by the skin. However, any source of radiation incorporated in the body is potentially hazardous. The large quality factor for alpha particles, for example, indicates that they are especially hazardous internally where they can deposit a large quantity of energy in a small amount of sensitive body tissue.

C. Common Sources of Exposure

Natural background radiation originating primarily from cosmic rays and terrestrial gamma emitters constitutes a significant source of radiation exposure to the general population. The dose from these background sources will vary because of altitude, latitude, and differences in radioactive material content of the soil. Cosmic radiation, for example, increases by a factor of three in going from sea level to 10,000 feet.[5] Consequently, the individual dose from these sources will vary considerably with location. A person in Louisiana or Texas will receive about 100 mrem (1 mrem = 0.001 rem) per year as compared to the 250 mrem annual dose received by a person in Colorado or Wyoming. Internal exposures also arise from body deposition of naturally-occuring radionuclides that have been ingested or inhaled. The major contributor from ingestion is potassium-40, whereas radon and its daughter products are the principal sources from inhalation. Estimated annual average individual whole-body doses from natural radiation in the United States are summarized in Table III-2.

Table III-2

Annual Average Doses from Natural Radiation Sources in the United States[5]

Source	Annual Doses (mrem)
Cosmic Rays	44
Terrestrial Radiation:	
External	40
Internal	18
TOTAL	102

Radiation exposure to the public also results from medical and dental treatment. The largest component of this dose results from diagnostic use of medical and dental x-rays. A smaller but growing contribution results from the use of radiopharmaceuticals.

Other sources of radiation leading to exposure of the general population are the nuclear power industry and the continuing worldwide fallout from atmospheric nuclear testing. Certain members of the population are also exposed to radiation as a result of their occupation.

A summary of all the common sources of radiation exposure is shown in Table III-3.

Table III-3

Estimates of Annual Whole-Body Dose to an Average Individual in the United States from Common Sources[5]

Source	Average Dose (mrem)
Environmental:	
Natural	102
Global Fallout	4
Nuclear Power	0.003
Medical:	
Diagnostic	72
Radiopharmaceuticals	1
Occupational:	0.8
Miscellaneous:	2.0
TOTAL	182

The rather small contributions from nuclear power and radiopharmaceuticals are expected to grow in the future with the expanding energy and medical needs of society.

D. Hazards from Radiation

Radiation can damage or destroy cells in the body. Altered cells can reproduce differently, increasing the possibilities for the development of cancer. Altered cells, when involved in reproduction, can produce genetic effects felt in subsequent generations.

Damage caused is a function of the type of radiation, the amount of radiation absorbed, and the time over which the dose is accumulated. Short term (or "acute") doses may have different effects from comparable doses received over longer periods ("chronic" doses).

Information on these effects is derived, in part, from experiments on animals and fruit flies.[5] Information on direct effects on man is largely restricted to data from Japanese atomic bomb casualties. This data, when combined with experience from radiation therapy and the few nuclear [illegible] accident cases, shows that large acute doses can produce discernible symptoms (known collectively as radiation sickness). A summary of these large acute dose effects is given in Table III-4.

Cells and organs of the human body vary in their sensitivity to radiation. The reproductive organs are among the more sensitive. Radiation doses to males beginning above 10 rads and extending to 600 rads produce a decrease in, or absence of, sperm beginning six to seven weeks after exposure and continuing for a few months to several years, after which there is full recovery. The extent of sperm count decrease and the ratio of return are related to the magnitude of the exposure. It should be noted, however, that even the maximum experimental dose (600 rads) did <u>not</u> produce permanent sterility.[18]

Table III-4

Dose-Effect Relationships in Man for Whole-Body Gamma Irradiation[6,18]

Dose (rads)	Nature of Effect
5-25	Minimum detectable dose by chromosome analysis or other specialized tests.
50-75	Minimum acute dose readily detectable in a specific individual.
75-125	Minimum acute dose likely to produce vomiting in about 10% of people so exposed.
150-200	Acute dose likely to produce transient disability and obvious blood changes in a majority of people exposed.
340	Median lethal dose for single, short exposure with no medical treatment.

Fortunately, large acute exposures to radiation are only characteristic of accidents, nuclear warfare situations, or radiation therapy. More typical to mankind's situation is exposure to low-level chronic radiation. The long-term consequences of such exposures are more difficult to ascertain, but the body repair mechanism does appear to operate to mitigate the effects of low-level, chronic exposure. The harmful effects this exposure may have on the human body are often difficult to separate from similar effects produced by certain chemicals and other environmental hazards. Special studies such as the BEIR report[5] have extrapolated from Japanese atomic bomb casualty data to estimate the risk from low-level radiation in terms of additional cancer fatalities. These results have been used in the Health Effects Model for this study (see Section H of this chapter).

Besides cancer, genetic effects are thought to be another possible long-term consequence of radiation exposure, although virtually no data exist on human beings. It is known that radiation can cause mutations in lower life forms, and that most of these mutations are unfavorable. One might expect a shorter life-span in future generations as evidence of deleterious genetic effects. On the contrary, however, exposures at dose rates of 0.1 to 0.5 rad per day have consistently resulted in an increase of the average life span in rodents[6] and have increased the fecundity of certain fish,[8] for reasons not completely understood.

E. Radiation Standards

As a result of the early injuries and deaths from contact with radioactivity and excessive exposure to x rays, international efforts were organized during the early 1920's to establish standards for radiation protection. In 1928, the International Committee (now Commission) on Radiation

Protection (ICRP) was created. In the United States, a group called the Advisory Committee on X Ray and Radium Protection, later to become the National Council on Radiation Protection and Measurements (NCRP), was organized in 1929. More recently, the Federal Government entered the field of radiation protection through the Federal Radiation Council (FRC), whose functions were transferred to the Environmental Protection Agency (EPA) in 1970. The dose limits proposed by NCRP and adopted by EPA are tabulated in Table III-5.

It can be noted from the table that the recommended population dose limitation, for example, is 0.17 rem average whole-body dose per person per year. That value represents exposure from all sources except natural background radiation and medical procedures. Often, a maximum permissable concentration (MPC) in air or water may be stated for a given radionuclide. This is the maximum amount a person might be exposed to externally or internally without exceeding the recommended dose limitations. It should be noted that the levels noted in the table were suggested as upper limits, with the understanding that radiation exposure be kept as low as practicable. The recommended limiting levels (given in 10 CFR 20) are substantially below the level where harmful effects have been observed in humans.

F. Cost-Benefit

There is a certain amount of statistical risk involved with any level of exposure to radiation. In line with other

Table III-5

NCRP Dose-Limiting Recommendations[6]

Combined Whole-Body Occupational Exposure	
Prospective annual limit	5 rem in any one year (3/quarter)
Retrospective annual limit	10-15 rem in any one year
Long-term accumulation to age N years	(N-18) x 5 rem
Skin	15 rem in any one year
Forearms	30 rem in any one year (10/quarter)
Other organs, tissues, and organ systems	15 rem in any one year (5/quarter)
Fertile women (with respect to fetus)	0.5 rem in gestation period
Dose Limits for the Public or Occasionally Exposed Individuals	0.5 rem in any one year
Population Dose Limits	
Genetic	0.17 rem average/year
Somatic	0.17 rem average/year
Emergency Dose Limits - Life Saving	
Individual (older than 45 yrs., if possible)	100 rem
Hands and forearms	200 rem, additional (300 rem, total)
Emergency Dose Limits - Less Urgent	
Individual	25 rem
Hands and forearms	100 rem, total

activities and needs of society, one must compare the benefits gained from the use of radioactive substances with the possible risks entailed. Few people, for example, are likely to stop using medical x-rays or radiopharmaceuticals which may help discover a developing tumor for fear of the cell damage produced by the radiation. In short, benefits outweighing the prospective costs are usually expected from certain uses of radioactive substances, just as with many other hazardous materials. Similarly few people are likely to change their location to reduce background exposure, although this background can vary between certain states by as much as the recommended population maximum. In Table III-6 the risk of fatal cancer or life-span shortening from radiation is put into perspective with other risks commonly taken in our society.

Shielding can be introduced to reduce the external radiation hazard to the public. Typically, lead or other high atomic number material is used to shield against gamma rays; low atomic number material is used to shield against neutrons. Shielding can also be a factor in a cost-benefit analysis. For example, a radiopharmaceutical can only reasonably be shielded by lead to the point where its transportation is feasible or its weight is generally not cost-prohibitive.

G. Radiological Properties of Transported Radioisotopes

During the past 25 years, clinical applications of radioactive materials have become a major branch of medicine.[11] In particular, gamma-ray emitting isotopes

Table III-6

Average Number of Days Given Up for Various Activities[9]

Activity	Cost in Days of Life
Living in City (rather than country)	1800
Remaining unmarried	1800
Smoking 1 pack of cigarettes/ day	3000
Being ten pounds overweight	500
Using automobiles	240
170 mrem/year of radiation exposure	10

are now commonly used for the purpose of imaging specific areas or organs. The detection of the gamma emission greatly facilitates diagnosis of physiologic malformation or malfunction. Radioisotopes of iodine were among the first such materials. Their use in the study of thyroid physiology and in the diagnosis and treatment of thyroid disorders still make them an important part (300,000 administrations/year[12]) of the modern radiopharmaceutical industry. The growth rate of this industry is estimated at 30 percent annually in terms of the number of patients treated by this imaging technique.

An example of this growth is the increased application of technetium-99m, an unstable daughter of molybdenum-99. Technetium-99m has no application, in itself, as a natural component of any biologic system. Its desirable properties--a six-hour half-life and a 140-keV gamma ray emission well-matched to existing monitoring instruments--make it ideal for imaging. Radiochemists are, therefore, working hard to incorporate this isotope into medically useful forms. It is estimated that nearly 5.5 million examinations were performed in 1972 using technetium.[13] At present, the most useful form is as a pertechnetate, used for brain scanning (120,000 administrations/year). Technetium-99m can be given in rather large doses with little radiation exposure. A major source for technetium-99m is the molybdenum-99 generator or "cow" from which the daughter product is eluted--i.e. milked by flushing with a saline solution.[11]

Many other scanning procedures are now in use--Au^{198} or I^{131} for liver (61,000 administrations/year), I^{131} for

lungs (23,000 administrations/year, Hg^{203} for kidneys (16,000), Sr^{85} for bone (6,000), etc.

The high-energy gamma emission from certain radioisotopes makes them important in the radiography industry. The isotope Co^{60}, for example, emits high energy gamma rays well-suited to the analysis of thicknesses or flaws in metal objects. The isotope Ir^{192} is also a commonly used radiography source. These sources typically emit gamma rays of much higher energy than radiopharmaceuticals. They are also characterized by a much longer physical half-life. They are usually packaged in well-shielded, portable containers which allow them to be used in remote places.

Density variations may be measured by backscattering techniques, in which gamma rays interact with surrounding material. Substances involving Cs^{137} use this technique in oil-well logging to determine the soil or rock composition at various depths.

Various isotopes of uranium and plutonium are involved in the nuclear fuel cycle. These substances, basically alpha emitters, constitute special hazards to the body upon inhalation (see Appendix B). These materials can also lead to significant neutron emission when in a chemical form which favors the (α,n) reaction (a nuclear reaction in which an alpha particle interacts with another nucleus to release a neutron). Plutonium in the form of plutonium oxide embodies these hazards.

Transported isotopes which can have significant radiological effects are summarized in Table III-7. The relative hazards to man are a function of the type and energy of the radiation as well as the effective half-life of the radionuclide. Table III-7 shows that the effective half-life increases as one goes from radiopharmaceuticals, to radiographic sources, and finally to isotopes of uranium and plutonium. Some pertinent characteristics of plutonium are further discussed in Appendix B.

H. Health Effects Model

The health effects model used in this assessment is based on the detailed model developed in Appendix VI to WASH-1400.[18] Some additional simplifying assumptions were made to make the more detailed reactor accident analysis applicable to the transportation situation.

Potential dosage sources were first subdivided into external penetrating radiation sources (principally from normal transport as discussed in Chapter IV) and internal radiation sources (principally from inhalation following accidents as discussed in Chapter V).

External penetrating radiation presents a whole-body exposure problem from photons and neutrons with each organ receiving similar dosages.

Internal dose effects are dependent on the biological pathway taken by the radioactive specie in the body. In order to specify this pathway, the chemical nature of the

TABLE III-7

Summary of Radiobiological Properties of Some Transported Radionuclides

Radionuclides	Principle Radiation	Soluble or Insoluble	Half-Life (days) Radioactive	Biological	Effective*	Organ of Principal Interest	Rem/curie (inhaled)
Tc^{99m}	140 Kev gamma	S	.25	1.0	0.2	lung	89
Mo^{99}	1.2 Mev beta	S	2.79	5.0	1.8	lung	2.1×10^4
I^{131}	360 Kev gamma	S	8.05	138.0	7.6	thyroid	1.1×10^6 (adult)
Co^{60}**	1.1, 1.3 Mev gamma	I	**	**	**	**	**
Ir^{192}	.3, .5, .6 Mev gamma	I	**	**	**	**	**
U^{235}	4.5 Mev alpha	I	2.6×10^{11}	100	100	lung	43.1 (16)
PuO_2	~5.2 Mev alpha	I	8.9×10^6	500	500	lung,bone	2×10^8
Pu	~5.2 Mev alpha	S	8.9×10^6	7.3×10^4	7.3×10^4	bone	4.8×10^4 (ingested) 2×10^8 (inhaled)

*The time required for the amount of a given radioisotope to decrease to half its original value as a result of both radioactive decay and elimination.

**Principally an external penetrating radiation hazard due to shipment as special form material.

specie, in particular whether it is soluble or insoluble, must be specified. Additionally, for insoluble species, the mechanism by which the material enters the body (i.e., ingestion or inhalation) must be specified. Ingestion is considered a pathway only for long-term, low-level activity present in the diet.[18] An examination of the materials in the transportation analysis eliminates this pathway because the types of materials and amounts of these materials involved in accidents preclude significant food-chain buildup or resuspension. Inhalation is, therefore, left as the only significant internal dose mechanism. Solubility or insolubility is as determined from Table III-7 and rem per curie inhaled values for susceptible organs are tabulated in Table III-8.

In order to compare person-rem per year resulting from accidents involving various materials with exposure from external penetrating radiation resulting from normal transportation of radioactive materials, a common basis for comparison must be established. For the purposes of this assessment, the number of latent cancer fatalities (LCF) was chosen. Values for LCF reflecting the consequences of exposure to various organs are tabulated in Table III-9,[18] which assumes a linear dose effect extrapolation. For whole-body exposures, the LCF coefficient of 121.6 deaths per million person-rem (less thyroid) also from Table III-9 is used in the model.

In addition to latent cancer fatalities, the question of early fatality due to large doses over a short time period must be addressed. The two organs of particular

TABLE III-8 (18)

Dose-Conversion Factors for Inhaled Radionuclides
(rem per curie inhaled)

BODY ORGAN: TOTAL MARROW

Radionuclide	0-2 Days	0-7 Days	0-30 Days	0-1 Year	0-10 Years	0-30 Years	0-50 Years
CO-58	2.3E+02	4.0E+02	1.1E+03	3.0E+03	3.1E+03	3.1E+03	3.1E+03
CO-60	5.5E+02	1.2E+03	2.8E+03	2.1E+04	5.6E+04	5.8E+04	5.8E+04
KR-85	6.0E-01	6.1E-01	6.1E-01	6.1E-01	6.1E-01	6.1E-01	6.1E-01
KR-85M	3.9E-01	3.9E-01	3.9E-01	3.9E-01	3.9E-01	3.9E-01	3.9E-01
KR-87	1.3E+00	1.3E+00	1.3E+00	1.3E+00	1.3E+00	1.3E+00	1.3E+00
KR-88	3.1E+00	3.1E+00	3.1E+00	3.1E+00	3.1E+00	3.1E+00	3.1E+00
RB-86	5.0E+02	1.7E+03	4.8E+03	6.5E+03	6.5E+03	6.5E+03	6.5E+03
SR-89	5.2E+02	1.7E+03	5.0E+03	1.3E+04	1.3E+04	1.3E+04	1.3E+04
SR-90	3.6E+02	2.2E+03	1.0E+04	1.1E+05	5.3E+05	6.9E+05	7.3E+05
SR-91	1.9E+02	2.0E+02	2.3E+02	3.1E+02	3.2E+02	3.2E+02	3.2E+02
Y-90	2.0E+02	4.3E+02	5.1E+02	5.1E+02	5.1E+02	5.1E+02	5.1E+02
Y-91	1.6E+02	5.7E+02	2.3E+03	9.2E+03	9.3E+03	9.3E+03	9.3E+03
ZR-95	1.8E+02	4.0E+02	9.4E+02	3.5E+03	3.6E+03	3.6E+03	3.6E+03
ZR-97	1.7E+02	1.9E+02	1.9E+02	1.9E+02	1.9E+02	1.9E+02	1.9E+02
NB-95	1.8E+02	3.8E+02	7.7E+02	1.4E+03	1.4E+03	1.4E+03	1.4E+03
MO-99	7.5E+01	1.2E+02	1.3E+02	1.3E+02	1.3E+02	1.3E+02	1.3E+02
TC-99M	1.1E+01	1.1E+01	1.1E+01	1.1E+01	1.1E+01	1.1E+01	1.1E+01
RU-103	1.3E+02	2.6E+02	5.5E+02	1.1E+03	1.1E+03	1.1E+03	1.1E+03
RU-105	2.3E+01	2.4E+01	2.4E+01	2.4E+01	2.4E+01	2.4E+01	2.4E+01
RU-106	7.6E+01	3.3E+02	6.6E+02	3.6E+03	6.2E+03	6.2E+03	6.2E+03
RH-105	1.6E+01	2.3E+01	2.3E+01	2.3E+01	2.3E+01	2.3E+01	2.3E+01
TE-127	3.7E+00	3.9E+00	3.9E+00	3.9E+00	3.9E+00	3.9E+00	3.9E+00
TE-127M	2.6E+01	9.5E+01	2.7E+02	7.5E+02	8.0E+02	8.0E+02	8.0E+02
TE-129	1.1E+00	1.1E+00	1.1E+00	1.1E+00	1.1E+00	1.1E+00	1.1E+00
TE-129M	6.7E+01	2.2E+02	5.3E+02	8.3E+02	8.4E+02	8.4E+02	8.4E+02
TE-131M	2.1E+02	2.9E+02	3.1E+02	3.1E+02	3.1E+02	3.1E+02	3.1E+02
TE-132	4.[illegible]02	8.8E+02	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03
SB-127	1.7[illegible]+02	2.9E+02	3.3E+02	3.3E+02	3.3E+02	3.3E+02	3.3E+02
SB-129	4.5E+01	4.6E+01	4.6E+01	4.6E+01	4.6E+01	4.6E+01	4.6E+01
I-131	7.7E+01	1.2E+02	1.8E+02	1.9E+02	1.9E+02	1.9E+02	1.9E+02
I-132	5.0E+01	5.0E+01	5.0E+01	5.0E+01	5.0E+01	5.0E+01	5.0E+01
I-133	8.8E+01	9.3E+01	9.4E+01	9.4E+01	9.4E+01	9.4E+01	9.4E+01
I-134	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01
I-135	9.1E+01	9.1E+01	9.1E+01	9.1E+01	9.1E+01	9.1E+01	9.1E+01
XE-133	1.5E+00	1.6E+00	1.6E+00	1.6E+00	1.6E+00	1.6E+00	1.6E+00
XE-135	2.1E+00	2.1E+00	2.1E+00	2.1E+00	2.1E+00	2.1E+00	2.1E+00
CS-134	5.8E+02	2.0E+03	7.0E+03	4.3E+04	4.8E+04	4.8E+04	4.8E+04
CS-136	6.9E+02	2.1E+03	5.0E+03	6.0E+03	6.0E+03	6.0E+03	6.0E+03
CS-137	3.6E+02	1.3E+03	5.2E+03	3.1E+04	3.7E+04	3.7E+04	3.7E+04
BA-140	4.8E+02	1.4E+03	2.9E+03	3.4E+03	3.4E+03	3.4E+03	3.4E+03
LA-140	4.4E+02	6.6E+02	6.8E+02	6.8E+02	6.8E+02	6.8E+02	6.8E+02
CE-141	3.7E+01	7.6E+01	1.5E+02	2.7E+02	2.7E+02	2.7E+02	2.7E+02
CE-143	6.6E+01	9.1E+01	1.8E+02	1.1E+02	1.1E+02	1.1E+02	1.1E+02
CE-144	6.2E+01	1.2E+02	3.5E+02	3.6E+03	9.2E+03	9.2E+03	9.2E+03
PR-143	3.0E+00	9.6E+00	2.6E+01	3.4E+01	3.4E+01	3.4E+01	3.4E+01
ND-147	5.5E+01	1.1E+02	1.7E+02	1.9E+02	2.0E+02	2.0E+02	2.0E+02
NP-239	4.0E+01	6.0E+01	6.4E+01	6.4E+01	6.4E+01	6.4E+01	6.4E+01
PU-238	1.8E+01	6.3E+01	2.8E+02	6.0E+03	2.3E+05	8.7E+05	1.3E+06
PU-239	1.6E+01	5.8E+01	2.6E+02	5.6E+03	2.3E+05	9.2E+05	1.5E+06
PU-240	1.6E+01	5.8E+01	2.6E+02	5.6E+03	2.3E+05	9.2E+05	1.5E+06
PU-241	3.3E-03	1.2E-02	7.2E-02	6.1E+00	1.8E+03	1.5E+04	3.2E+04
AM-241	4.0E+01	1.1E+02	4.2E+02	7.2E+03	2.5E+05	9.0E+05	1.6E+06
CM-242	2.1E+01	7.6E+01	3.3E+02	3.2E+03	6.1E+03	8.5E+03	1.0E+04
CM-244	2.0E+01	7.3E+01	3.3E+02	6.6E+03	2.1E+05	5.8E+05	7.4E+05

TABLE III-8

BODY ORGAN: LUNG

Radionuclide	0-2 Days	0-7 Days	0-30 Days	0-1 Year	0-10 Years	0-30 Years	0-50 Years
CO-58	1.9E+03	5.2E+03	1.7E+04	5.9E+04	6.1E+04	6.1E+04	6.1E+04
CO-60	4.8E+03	1.3E+04	4.9E+04	4.6E+05	1.2E+06	1.3E+06	1.3E+06
KR-85	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01
KR-85M	2.1E-01	2.1E-01	2.1E-01	2.1E-01	2.1E-01	2.1E-01	2.1E-01
KR-87	9.6E-01	9.6E-01	9.6E-01	9.6E-01	9.6E-01	9.6E-01	9.6E-01
KR-88	2.0E+00	2.0E+00	2.0E+00	2.0E+00	2.0E+00	2.0E+00	2.0E+00
RB-86	7.2E+03	9.0E+03	1.2E+04	1.4E+04	1.4E+04	1.4E+04	1.4E+04
SR-89	6.0E+03	6.8E+03	7.2E+03	7.8E+03	7.8E+03	7.8E+03	7.8E+03
SR-90	4.6E+03	9.3E+03	1.2E+04	1.6E+04	1.8E+04	1.8E+04	1.8E+04
SR-91	3.4E+03	3.5E+03	3.8E+03	4.3E+03	4.3E+03	4.3E+03	4.3E+03
Y-90	1.7E+04	2.9E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04	3.3E+04
Y-91	1.3E+04	3.5E+04	1.0E+05	2.0E+05	2.0E+05	2.0E+05	2.0E+05
ZR-95	3.5E+03	9.7E+03	3.4E+04	1.3E+05	1.3E+05	1.3E+05	1.3E+05
ZR-97	1.4E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04
NB-95	1.8E+03	4.9E+03	1.5E+04	3.1E+04	3.1E+04	3.1E+04	3.1E+04
MO-99	7.7E+03	1.4E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04
TC-99M	8.9E+01	8.9E+01	8.9E+01	8.9E+01	8.9E+01	8.9E+01	8.9E+01
RU-103	2.9E+03	7.6E+03	2.4E+04	5.4E+04	5.4E+04	5.4E+04	5.4E+04
RU-105	2.1E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03	2.2E+03
RU-106	3.3E+04	9.1E+04	3.3E+05	2.5E+06	3.9E+06	3.9E+06	3.9E+06
RH-105	2.5E+03	3.5E+03	3.6E+03	3.6E+03	3.6E+03	3.6E+03	3.6E+03
TE-127	1.5E+03	1.6E+03	1.6E+03	1.6E+03	1.6E+03	1.6E+03	1.6E+03
TE-127M	5.2E+03	1.6E+04	5.2E+04	1.2E+05	1.2E+05	1.2E+05	1.2E+05
TE-129	5.6E+02	5.6E+02	5.6E+02	5.6E+02	5.6E+02	5.6E+02	5.6E+02
TE-129M	1.3E+04	3.5E+04	9.5E+04	1.5E+05	1.5E+05	1.5E+05	1.5E+05
TE-131M	6.6E+03	9.4E+03	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04
TE-132	1.3E+04	2.4E+04	3.0E+04	3.0E+04	3.0E+04	3.0E+04	3.0E+04
SB-127	9.1E+03	1.9E+04	2.4E+04	2.5E+04	2.5E+04	2.5E+04	2.5E+04
SB-129	3.1E+03	3.1E+03	3.1E+03	3.2E+03	3.2E+03	3.2E+03	3.2E+03
I-131	2.1E+03	2.3E+03	2.4E+03	2.4E+03	2.4E+03	2.4E+03	2.4E+03
I-132	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03
I-133	3.1E+03	3.1E+03	3.1E+03	3.1E+03	3.1E+03	3.1E+03	3.1E+03
I-134	5.6E+02	5.6E+02	5.6E+02	5.6E+02	5.6E+02	5.6E+02	5.6E+02
I-135	2.5E+03	2.5E+03	2.5E+03	2.5E+03	2.5E+03	2.5E+03	2.5E+03
XE-133	4.1E-01	4.1E-01	4.1E-01	4.1E-01	4.1E-01	4.1E-01	4.1E-01
XE-135	9.4E-01	9.4E-01	9.4E-01	9.4E-01	9.4E-01	9.4E-01	9.4E-01
CS-134	3.0E+03	4.7E+03	1.1E+04	4.5E+04	5.1E+04	5.1E+04	5.1E+04
CS-136	2.9E+03	4.5E+03	7.3E+03	8.2E+03	8.2E+03	8.2E+03	8.2E+03
CS-137	3.2E+03	4.4E+03	8.3E+03	3.4E+04	4.0E+04	4.0E+04	4.0E+04
BA-140	4.6E+03	5.7E+03	6.1E+03	6.3E+03	6.3E+03	6.3E+03	6.3E+03
LA-140	1.0E+04	1.5E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04	1.6E+04
CE-141	4.0E+03	1.0E+04	3.1E+04	6.2E+04	6.2E+04	6.2E+04	6.2E+04
CE-143	7.0E+03	1.0E+04	1.2E+04	1.3E+04	1.3E+04	1.3E+04	1.3E+04
CE-144	2.9E+04	8.2E+04	3.0E+05	2.1E+06	2.9E+06	2.9E+06	2.9E+06
PR-143	6.9E+03	1.7E+04	4.0E+04	4.9E+04	4.9E+04	4.9E+04	4.9E+04
ND-147	6.1E+03	1.5E+04	3.1E+04	3.7E+04	3.8E+04	3.8E+04	3.8E+04
NP-239	5.0E+03	8.3E+03	9.2E+03	9.2E+03	9.3E+03	9.3E+03	9.3E+03
PU-238	1.3E+06	3.6E+06	1.3E+07	1.2E+08	3.1E+08	3.1E+08	3.1E+08
PU-239	1.2E+06	3.3E+06	1.2E+07	1.2E+08	2.9E+08	2.9E+08	2.9E+08
PU-240	1.2E+06	3.3E+06	1.2E+07	1.2E+08	2.9E+08	2.9E+08	2.9E+08
PU-241	1.3E+02	3.7E+02	1.3E+03	6.4E+04	5.3E+05	5.7E+05	5.9E+05
AM-241	1.3E+06	3.6E+06	1.3E+07	1.3E+08	3.1E+08	3.1E+08	3.1E+08
CM-242	1.4E+06	3.9E+06	1.4E+07	7.6E+07	8.7E+07	8.7E+07	8.7E+07
CM-244	1.4E+06	3.8E+06	1.4E+07	1.3E+08	3.1E+08	3.1E+08	3.1E+08

TABLE III-8

BODY ORGAN: SKELETON

Radionuclide	0-2 Days	0-7 Days	0-30 Days	0-1 Year	0-10 Years	0-30 Years	0-50 Years
CO-58	1.5E+02	3.3E+02	8.4E+02	2.5E+03	2.6E+03	2.6E+03	2.6E+03
CO-60	3.5E+02	8.0E+02	2.2E+03	1.8E+04	4.3E+04	5.0E+04	5.0E+04
KR-85	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01
KR-85M	1.9E-01	1.9E-01	1.9E-01	1.9E-01	1.9E-01	1.9E-01	1.9E-01
KR-87	8.3E-01	8.3E-01	8.3E-01	8.3E-01	8.3E-01	8.3E-01	8.3E-01
KR-88	1.8E+00	1.8E+00	1.8E+00	1.8E+00	1.8E+00	1.8E+00	1.8E+00
RB-86	5.0E+02	1.7E+03	4.8E+03	6.5E+03	6.5E+03	6.5E+03	6.5E+03
SR-89	7.2E+02	3.0E+03	1.0E+04	3.0E+04	3.0E+04	3.0E+04	3.0E+04
SR-90	5.3E+02	3.8E+03	2.1E+04	2.3E+05	1.6E+06	2.4E+06	2.9E+06
SR-91	1.9E+02	2.0E+02	2.3E+02	3.4E+02	3.4E+02	3.4E+02	3.4E+02
Y-90	4.1E+02	8.6E+02	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03
Y-91	3.4E+02	1.2E+03	4.7E+03	1.9E+04	1.9E+04	1.9E+04	1.9E+04
ZR-95	1.2E+02	2.3E+02	7.9E+02	3.3E+03	3.4E+03	3.4E+03	3.4E+03
ZR-97	1.2E+02	1.3E+02	1.3E+02	1.3E+02	1.3E+02	1.3E+02	1.3E+02
NB-95	1.2E+02	2.6E+02	6.2E+02	1.2E+03	1.2E+03	1.2E+03	1.2E+03
MO-99	6.2E+01	1.0E+02	1.1E+02	1.1E+02	1.1E+02	1.1E+02	1.1E+02
TC-99M	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+01
RU-103	7.7E+01	1.8E+02	4.3E+02	8.8E+02	8.8E+02	8.8E+02	8.8E+02
RU-105	1.6E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01
RU-106	5.8E+01	1.9E+02	6.0E+02	3.4E+03	5.9E+03	5.9E+03	5.9E+03
RH-105	1.1E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01
TE-127	5.0E+00	5.2E+00	5.2E+00	5.2E+00	5.2E+00	5.2E+00	5.2E+00
TE-127M	3.1E+01	1.3E+02	4.4E+02	1.8E+03	2.0E+03	2.0E+03	2.0E+03
TE-129	1.2E+00	1.2E+00	1.2E+00	1.2E+00	1.2E+00	1.2E+00	1.2E+00
TE-129M	7.5E+01	2.6E+02	7.5E+02	1.4E+03	1.4E+03	1.4E+03	1.4E+03
TE-131M	1.6E+02	2.3E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02	2.5E+02
TE-132	4.4E+02	8.0E+02	9.1E+02	9.1E+02	9.1E+02	9.1E+02	9.1E+02
SB-127	1.2E+02	2.1E+02	2.5E+02	2.6E+02	2.6E+02	2.6E+02	2.6E+02
SB-129	3.8E+01	3.8E+01	3.8E+01	3.9E+01	3.9E+01	3.9E+01	3.9E+01
I-131	7.6E+01	1.2E+02	2.0E+02	2.1E+02	2.1E+02	2.1E+02	2.1E+02
I-132	4.7E+01	4.7E+01	4.7E+01	4.7E+01	4.7E+01	4.7E+01	4.7E+01
I-133	8.7E+01	9.2E+01	9.2E+01	9.2E+01	9.2E+01	9.2E+01	9.2E+01
I-134	1.9E+01	1.9E+01	1.9E+01	1.9E+01	1.9E+01	1.9E+01	1.9E+01
I-135	8.7E+01	8.7E+01	8.7E+01	8.7E+01	8.7E+01	8.7E+01	8.7E+01
XE-133	3.5E-01	3.6E-01	3.6E-01	3.6E-01	3.6E-01	3.6E-01	3.6E-01
XE-135	7.2E-01	7.2E-01	7.2E-01	7.2E-01	7.2E-01	7.2E-01	7.2E-01
CS-134	5.7E+02	2.0E+03	7.8E+03	4.2E+04	4.7E+04	4.7E+04	4.7E+04
CS-136	6.6E+02	2.0E+03	4.9E+03	5.9E+03	5.9E+03	5.9E+03	5.9E+03
CS-137	3.6E+02	1.3E+03	5.1E+03	3.1E+04	3.6E+04	3.6E+04	3.6E+04
BA-140	6.1E+02	2.0E+03	4.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03
LA-140	4.2E+02	6.7E+02	7.0E+02	7.0E+02	7.0E+02	7.0E+02	7.0E+02
CE-141	2.5E+01	6.1E+01	1.6E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02
CE-143	4.7E+01	7.1E+01	9.4E+01	1.1E+02	1.1E+02	1.1E+02	1.1E+02
CE-144	1.9E+02	2.0E+02	6.3E+02	7.2E+03	1.9E+04	1.9E+04	1.9E+04
PR-143	7.0E+00	2.4E+01	6.5E+01	8.6E+01	8.6E+01	8.6E+01	8.6E+01
ND-147	3.8E+01	8.5E+01	1.6E+02	1.9E+02	2.3E+02	2.4E+02	2.4E+02
NP-239	3.0E+01	4.9E+01	5.4E+01	5.4E+01	8.0E+01	1.6E+02	2.3E+02
PU-238	9.9E+03	3.5E+04	1.6E+05	3.4E+06	1.3E+08	4.9E+08	7.6E+08
PU-239	9.2E+03	3.3E+04	1.5E+05	3.1E+06	1.3E+08	5.2E+08	8.7E+08
PU-240	9.2E+03	3.3E+04	1.5E+05	3.1E+06	1.3E+08	5.2E+08	8.7E+08
PU-241	2.4E-01	1.2E+00	1.3E+01	2.7E+03	9.8E+05	8.3E+06	1.7E+07
AM-241	1.3E+04	3.9E+04	1.8E+05	3.6E+06	1.4E+08	5.5E+08	9.0E+08
CM-242	1.2E+03	4.3E+04	1.8E+05	1.8E+06	3.4E+06	4.8E+06	5.8E+06
CM-244	1.3E+04	4.1E+04	1.9E+05	3.7E+06	1.2E+08	3.3E+08	4.2E+08

TABLE III-8

BODY ORGAN: LOWER LARGE INTESTINE WALL

RADIONUCLIDE	0-2 Days	0-7 Days	0-30 Days	0-60 Days
CO-58	3.2E+03	6.9E+03	7.1E+03	7.2E+03
CO-60	8.0E+03	1.8E+04	1.8E+04	1.9E+04
KR-85	1.8E-01	1.8E-01	1.8E-01	1.8E-01
KR-85M	2.2E-01	2.2E-01	2.2E-01	2.2E-01
KR-87	1.0E+00	1.0E+00	1.0E+00	1.0E+00
KR-88	2.3E+00	2.3E+00	2.3E+00	2.3E+00
RB-86	1.2E+03	2.7E+03	5.8E+03	7.1E+03
SR-89	9.2E+03	1.4E+04	1.4E+04	1.4E+04
SR-90	7.3E+03	1.4E+04	1.6E+04	1.6E+04
SR-91	2.4E+03	2.6E+03	2.6E+03	2.6E+03
Y-90	2.2E+04	4.0E+04	4.0E+04	4.0E+04
Y-91	2.0E+04	4.6E+04	4.9E+04	5.0E+04
ZR-95	6.1E+03	1.4E+04	1.4E+04	1.5E+04
ZR-97	1.5E+04	1.9E+04	1.9E+04	1.9E+04
NB-95	3.2E+03	6.9E+03	7.0E+03	7.1E+03
MO-99	1.2E+04	2.0E+04	2.1E+04	2.1E+04
TC-99M	1.1E+01	1.1E+01	1.1E+01	1.1E+01
RU-103	4.8E+03	1.0E+04	1.1E+04	1.1E+04
RU-105	9.1E+02	1.2E+03	1.2E+03	1.2E+03
RU-106	5.5E+04	1.2E+05	1.3E+05	1.3E+05
RH-105	3.3E+03	5.1E+03	5.1E+03	5.1E+03
TE-127	7.3E+02	7.8E+02	7.8E+02	7.8E+02
TE-127M	6.9E+03	1.7E+04	2.0E+04	2.1E+04
TE-129	5.7E+00	5.7E+00	5.7E+00	5.7E+00
TE-129M	1.5E+04	3.4E+04	3.6E+04	3.7E+04
TE-131M	5.8E+03	8.5E+03	8.5E+03	8.5E+03
TE-132	3.3E+03	6.0E+03	6.1E+03	6.1E+03
SB-127	1.3E+04	2.6E+04	2.6E+04	2.6E+04
SB-129	7.0E+02	8.1E+02	8.1E+02	8.1E+02
I-131	2.6E+02	3.3E+02	3.6E+02	3.6E+02
I-132	6.0E+01	6.0E+01	6.0E+01	6.0E+01
I-133	2.8E+02	3.3E+02	3.3E+02	3.3E+02
I-134	2.0E+01	2.0E+01	2.0E+01	2.0E+01
I-135	2.2E+02	2.2E+02	2.2E+02	2.2E+02
XE-133	4.2E-01	4.2E-01	4.2E-01	4.2E-01
XE-135	9.9E-01	9.9E-01	9.9E-01	9.9E-01
CS-134	9.0E+02	2.8E+03	1.0E+04	1.8E+04
CS-136	9.9E+02	2.8E+03	6.4E+03	7.5E+03
CS-137	6.8E+02	1.9E+03	6.3E+03	1.1E+04
BA-140	9.4E+03	1.6E+04	1.6E+04	1.6E+04
LA-140	1.3E+04	2.1E+04	2.1E+04	2.1E+04
CE-141	6.7E+03	1.5E+04	1.5E+04	1.5E+04
CE-143	9.8E+03	1.6E+04	1.6E+04	1.6E+04
CE-144	5.2E+04	1.2E+05	1.2E+05	1.2E+05
PR-143	1.2E+04	2.5E+04	2.5E+04	2.5E+04
ND-147	1.0E+04	2.1E+04	2.2E+04	2.2E+04
NP-239	7.4E+03	1.3E+04	1.3E+04	1.3E+04
PU-238	2.2E+04	5.0E+04	5.1E+04	5.2E+04
PU-239	2.0E+04	4.6E+04	4.7E+04	4.8E+04
PU-240	2.1E+04	4.7E+04	4.8E+04	4.9E+04
PU-241	2.1E+02	4.7E+02	4.8E+02	4.8E+02
AM-241	2.3E+04	5.2E+04	5.4E+04	5.5E+04
CM-242	2.4E+04	5.5E+04	5.6E+04	5.7E+04
CM-244	2.3E+04	5.2E+04	5.4E+04	5.5E+04

TABLE III-8

BODY ORGAN: THYROID

Radionuclide	0-2 Days	0-7 Days	0-30 Days	0-60 Days
CO-58	1.1E+02	2.0E+02	9.5E+02	1.6E+03
CO-60	2.4E+02	6.5E+02	2.3E+03	4.4E+03
KR-85	1.8E-01	1.8E-01	1.8E-01	1.8E-01
KR-85M	2.0E-01	2.0E-01	2.0E-01	2.0E-01
KR-87	9.7E-01	9.7E-01	9.7E-01	9.7E-01
KR-88	2.0E+00	2.0E+00	2.0E+00	2.0E+00
RB-86	5.0E+02	1.7E+03	4.9E+03	6.1E+03
SR-89	2.6E+02	5.0E+02	9.2E+02	1.2E+03
SR-90	1.8E+02	7.3E+02	1.9E+03	2.5E+03
SR-91	1.3E+02	1.4E+02	1.6E+02	1.7E+02
Y-90	8.2E+00	1.7E+01	2.1E+01	2.1E+01
Y-91	7.1E+00	2.5E+01	9.9E+01	1.9E+02
ZR-95	7.9E+01	2.2E+02	8.0E+02	1.5E+03
ZR-97	7.7E+01	8.6E+01	8.6E+01	8.6E+01
NB-95	8.1E+01	2.1E+02	6.4E+02	9.5E+02
MO-99	9.4E+01	1.4E+02	1.5E+02	1.5E+02
TC-99M	4.6E+01	4.6E+01	4.6E+01	4.6E+01
RU-103	5.2E+01	1.4E+02	4.3E+02	6.6E+02
RU-105	1.4E+01	1.5E+01	1.5E+01	1.5E+01
RU-106	4.8E+01	1.7E+02	6.2E+02	1.0E+03
RH-105	6.4E+00	9.6E+00	9.9E+00	9.9E+00
TE-127	2.9E+00	3.0E+00	3.0E+00	3.0E+00
TE-127M	1.6E+01	6.3E+01	1.6E+02	1.9E+02
TE-129	8.1E-01	8.1E-01	8.1E-01	8.1E-01
TE-129M	4.3E+01	1.4E+02	3.2E+02	3.7E+02
TE-131M	4.5E+03	3.4E+04	8.7E+04	9.5E+04
TE-132	4.8E+04	8.8E+04	9.7E+04	9.7E+04
SB-127	1.0E+02	1.8E+02	2.2E+02	2.2E+02
SB-129	3.7E+01	3.7E+01	3.8E+01	3.8E+01
I-131	1.3E+05	4.8E+05	1.0E+06	1.1E+06
I-132	6.6E+03	6.6E+03	6.6E+03	6.6E+03
I-133	1.2E+05	1.8E+05	1.8E+05	1.8E+05
I-134	1.1E+03	1.1E+03	1.1E+03	1.1E+03
I-135	4.3E+04	4.4E+04	4.4E+04	4.4E+04
XE-133	3.9E-01	4.0E-01	4.0E-01	4.0E-01
XE-135	9.1E-01	9.1E-01	9.1E-01	9.1E-01
CS-134	5.8E+02	2.0E+03	7.9E+03	1.4E+04
CS-136	6.9E+02	2.1E+03	5.0E+03	5.9E+03
CS-137	3.6E+02	1.3E+03	5.1E+03	9.5E+03
BA-140	2.2E+02	5.9E+02	1.0E+03	1.2E+03
LA-140	1.5E+02	2.2E+02	2.3E+02	2.3E+02
CE-141	6.0E+00	1.6E+01	4.6E+01	6.0E+01
CE-143	1.0E+01	2.4E+01	2.5E+01	2.5E+01
CE-144	2.1E+02	1.7E+03	4.5E+03	8.4E+03
PR-143	3.3E-02	2.0E-01	7.0E-01	9.0E-01
ND-147	1.2E+01	2.9E+01	6.0E+01	6.2E+01
NP-239	8.2E+00	1.4E+01	1.5E+01	1.5E+01
PU-238	1.8E+01	6.2E+01	2.8E+02	6.0E+02
PU-239	1.6E+01	5.8E+01	2.5E+02	5.6E+02
PU-240	1.6E+01	5.8E+01	2.6E+02	5.5E+02
PU-241	1.7E-03	6.0E-03	4.5E-02	1.4E-01
AM-241	2.0E+01	7.3E+01	3.3E+02	6.9E+02
CM-242	2.1E+01	7.5E+01	3.3E+02	6.5E+02
CM-244	2.0E+01	7.3E+01	3.3E+02	7.0E+02

TABLE III-9

EXPECTED LATENT CANCER FATALITIES PER 10^6 PERSON-REM EXPOSURE TO THE POPULATION[18]

Type of Cancer*	Expected Deaths per 10^6 Person-Rem
Leukemia	28.4
Lung	22.2
Stomach	10.2
Alimentary Canal	3.4
Pancreas	3.4
Breast	25.6
Bone	6.9
All Others	21.6
Whole Body	121.6
Thyroid**	13.4

*BEIR coefficients[18] for a 75-year lifetime of potential cancer development are used.

**for assumed average individual dose of 1500 rem

interest for early fatalities, using the assumptions of this analysis, are the bone marrow (the fatality probability versus dose curve is shown in Figure III-1), and the lungs (the fatality probability versus dose curve is shown in Figure III-2). The only incidences of early bone marrow fatalities within the constraints of this model would occur from large dosages from external penetrating radiation sources. Isotopes capable of causing early lung fatalities would include any inhaled specie providing a sufficient dose to the lungs (i.e., plutonium oxide). The LD 50/365 (lethal dose to 50% of exposed people within 365 days) for long-lived alpha emitters[19] is the basis for the curve plotted in dotted lines on Figure III-2. This aspect of the radioactive material shipment hazard is addressed in Chapter V of this assessment.

For the most part, the radioactive materials transported are relatively short half-life species. There are, however, a few exceptions such as plutonium-239, cesium-137, and cobalt-60. Because these isotopes have the potential for long residence time in the body, two dosages must be considered. The early dose is based on the rem/curie value for a one-year period. This dose is used to compute early fatalities using probabilities from Figures III-1 and III-2. The long-term dosage is based on the rem/curie value for a 50-year period. It is this dose which is used to predict latent cancer fatalities.

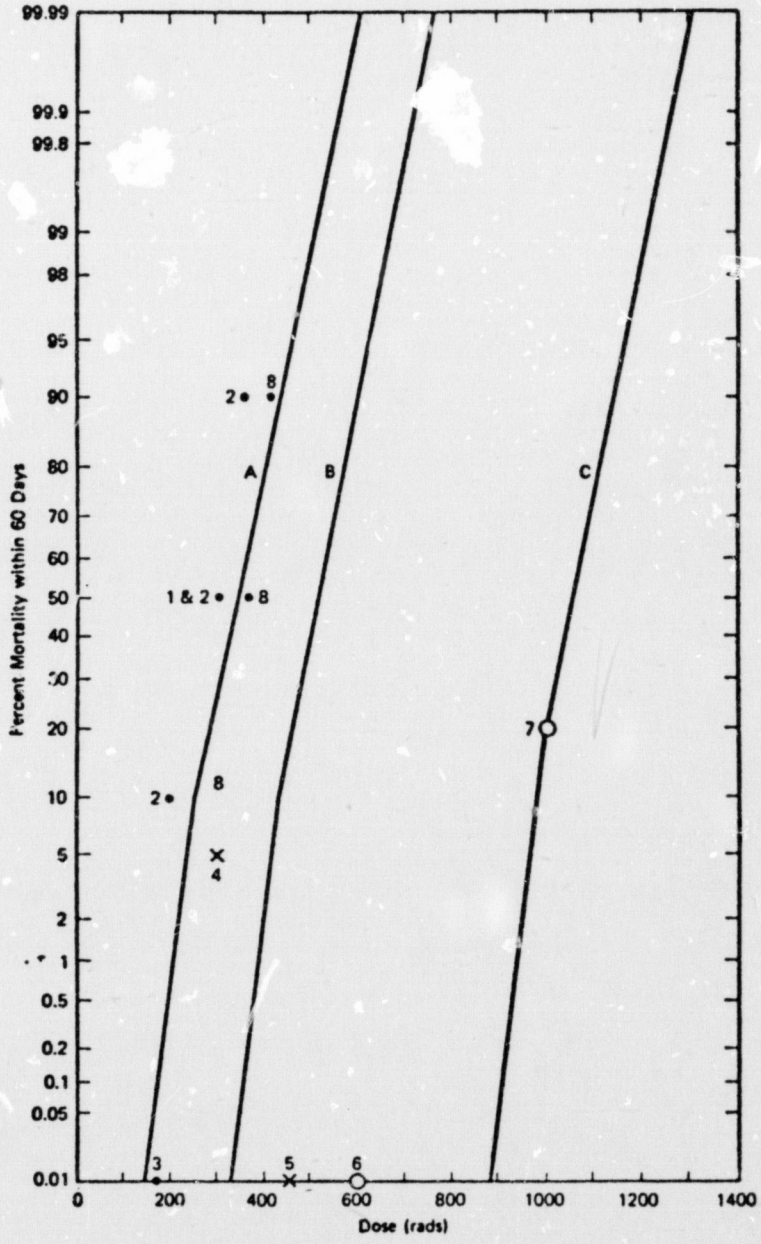

Figure III-1 Estimated dose-response curves for 50% mortality in 60 days with minimal treatment (curve A), supportive treatment (curve B), and heroic treatment (curve C). Origin of data points: 1, NCRP Report 42 (converted to rads using factor given in NCRP Report 42); 2, Langham (1967, Table 12, estimate for "normal man?"); 3, Marshall Islanders (protracted exposure); 4, radiation therapy series, 22 patients (Rider and Hasselback, 1968); 5, clinical group III accident patients (Thoma and Weld, 1959, with newer cases added); 6, Pittsburgh accelerator accident patient (E.D. Thomas, 1971; Weld, 1975); 7, 37 leukemia patients (E.D. Thomas, 1975); 8, "best estimate" of the Biomedical and Environmental Assessment Group at the Brookhaven National Laboratory.

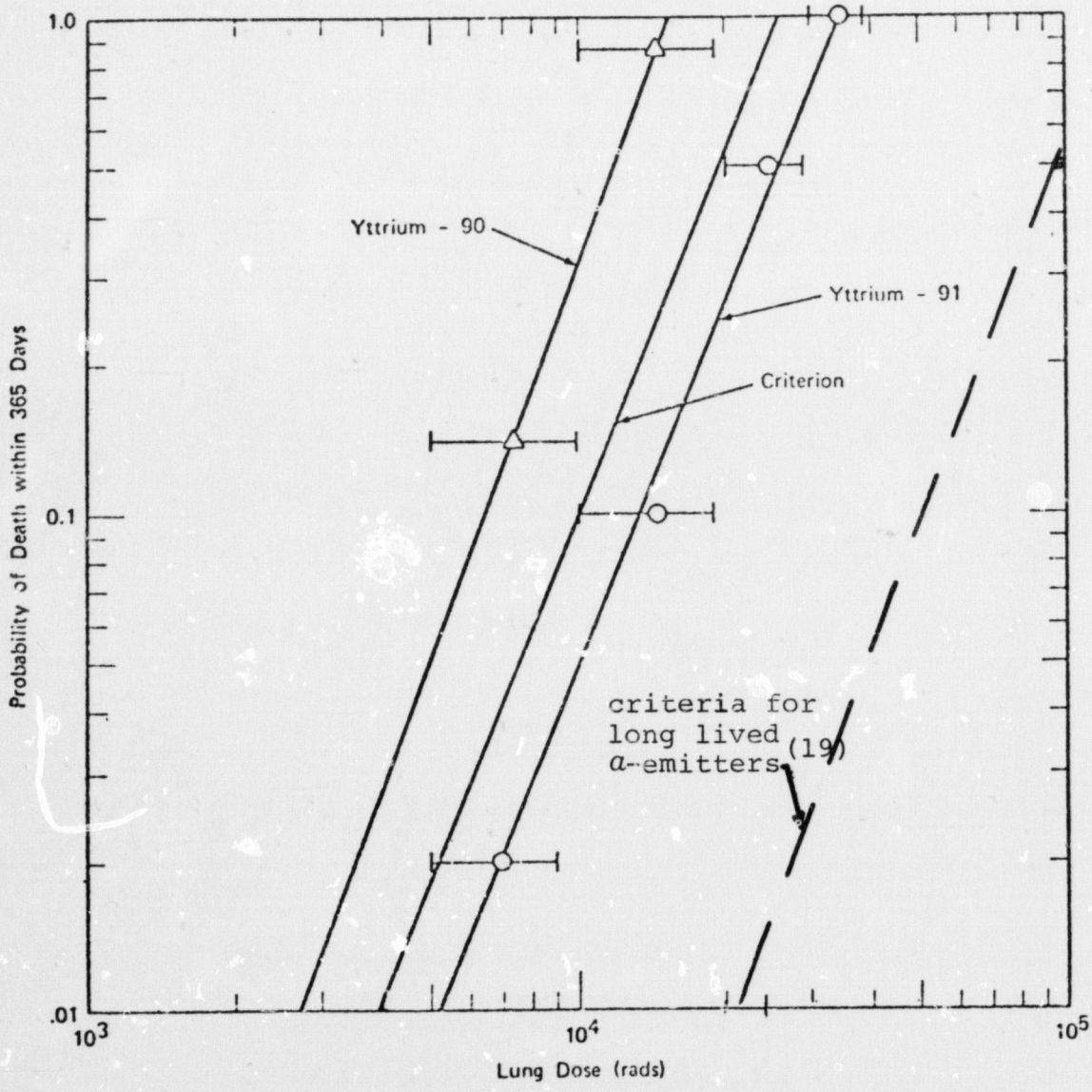

Figure III-2 Dose-response curves for yttrium-90 and yttrium-91.(18)*

*Yttrium-90 and 91 were the isotopes used in the experiment. The curve is equally valid for other radioactive materials.

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CHAPTER IV

TRANSPORT IMPACTS UNDER NORMAL CONDITIONS

A. Introduction

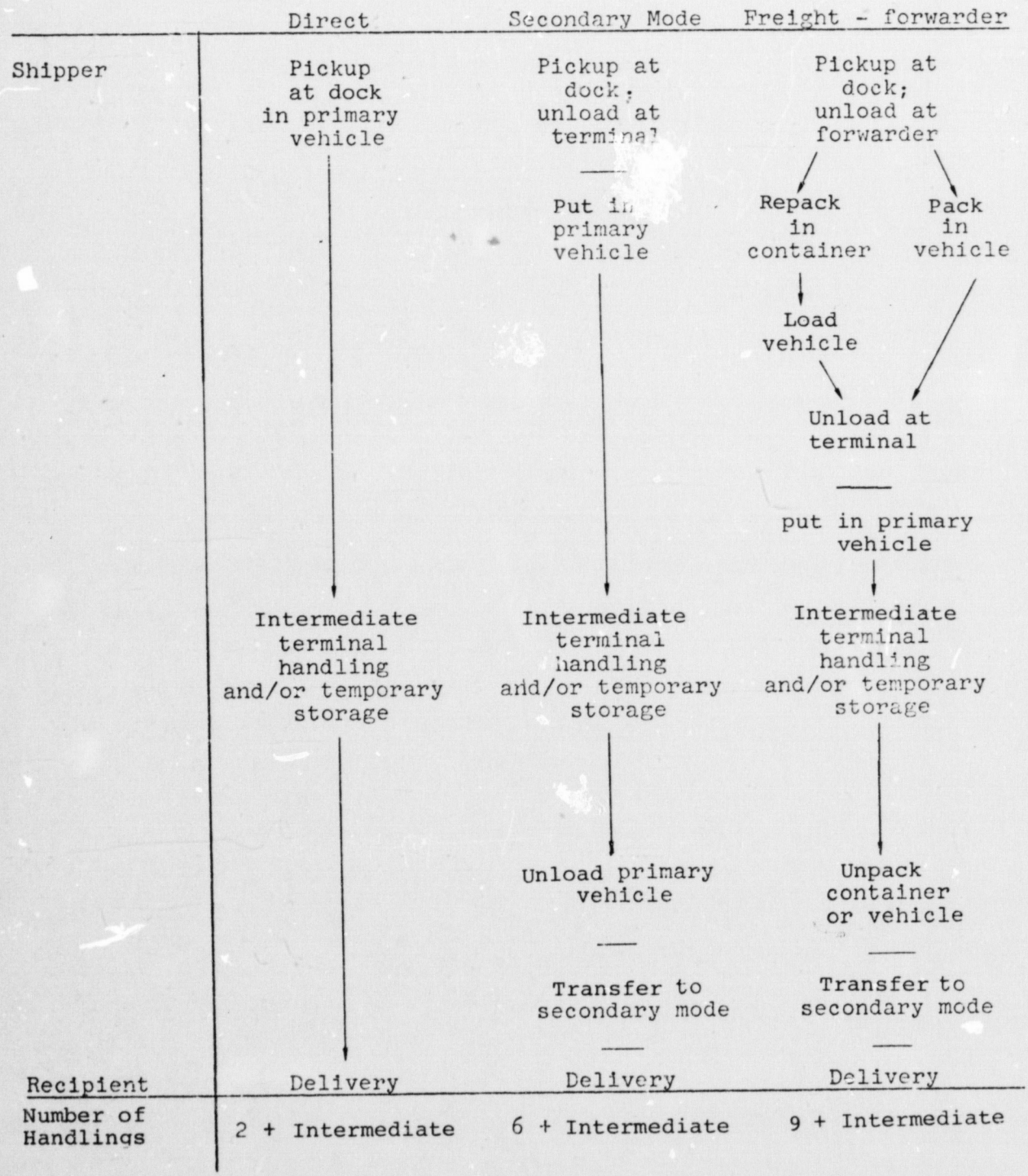
Normal transport of a radioactive material involves a wide range of events which can have environmental consequences. To make the source of these consequences clear, the sequence of events in shipping a radioactive material must be considered. First the material is placed in an approved package, the radiation exposure levels are noted, the package is labeled with the appropriate information, a shipping bill is prepared, and the package is put aside until the transportation process begins. From the moment the package begins moving toward its destination, it becomes a part of the subject of this assessment. This process is shown schematically in Figure IV-1.

The sequence may take one of several forms. The package might be loaded directly onto a vehicle which will take it to its ultimate destination. However, it is more likely that it will undergo a "secondary" mode of transport, that is, a truck or light duty vehicle will take the package to a terminal where it will be part of a sorting process and assigned with other parcels to a primary vehicle. This vehicle will take it to a terminal near its destination where it will undergo additional secondary mode transport in getting to its ultimate destination.

Another possible alternative is that the package will be picked up by or delivered to a freight forwarder who will include it in a shipment to a specific place. This shipment will consist of a large number of packages obtained from a number of different shippers. When the shipment arrives at its destination, it is separated into individual packages which are delivered to the consignees.

FIGURE IV-1

Schematic of Transport Operations



Naturally, there are various combinations of these three basic transport scenarios, but the shipping industry is modeled from these basic scenarios. The basic picture indicated in Figure IV-1 is independent of the primary mode of transport (air, rail, water, or truck) and thus allows some generality in the discussion of the events associated with radioactive material transport.

One method of representing the process by which an environmental impact is produced is depicted in Figure IV-2 which shows a portion of the logic model for the normal transport of radioactive material. The activities leading to the first tier event, N1, indicate the numerous pathways and events which lead to an environmental impact. The letter in the lower right in each box represents the appropriate section of the text which discusses the event or required input information.

Normal transport as defined here includes the processes described above and shown schematically in Figure IV-2 by events N2-1 to N2-4. When transport occurs in a timely manner with the package arriving at its destination undamaged and the radioactive material intact, it is defined as normal transport. However, normal transport also includes the less frequent cases where shipment may not be timely, or the package is damaged, or the contents are lost or destroyed. These latter cases are parts of the routine shipping cycle, and assessment of their environmental impact is included in Part F of this chapter. The remaining events on tier 2 of Figure IV-2 are considered in the following sections of this chapter.

B. Radiological Impact on Flora and Fauna

The principal emphasis of this study is direct impact upon man and his environment. But, as indicated in the logic model, there are impacts upon flora and fauna (event N2-2), upon objects (event N2-3), and indirect impacts on man (event N3-2) which must be

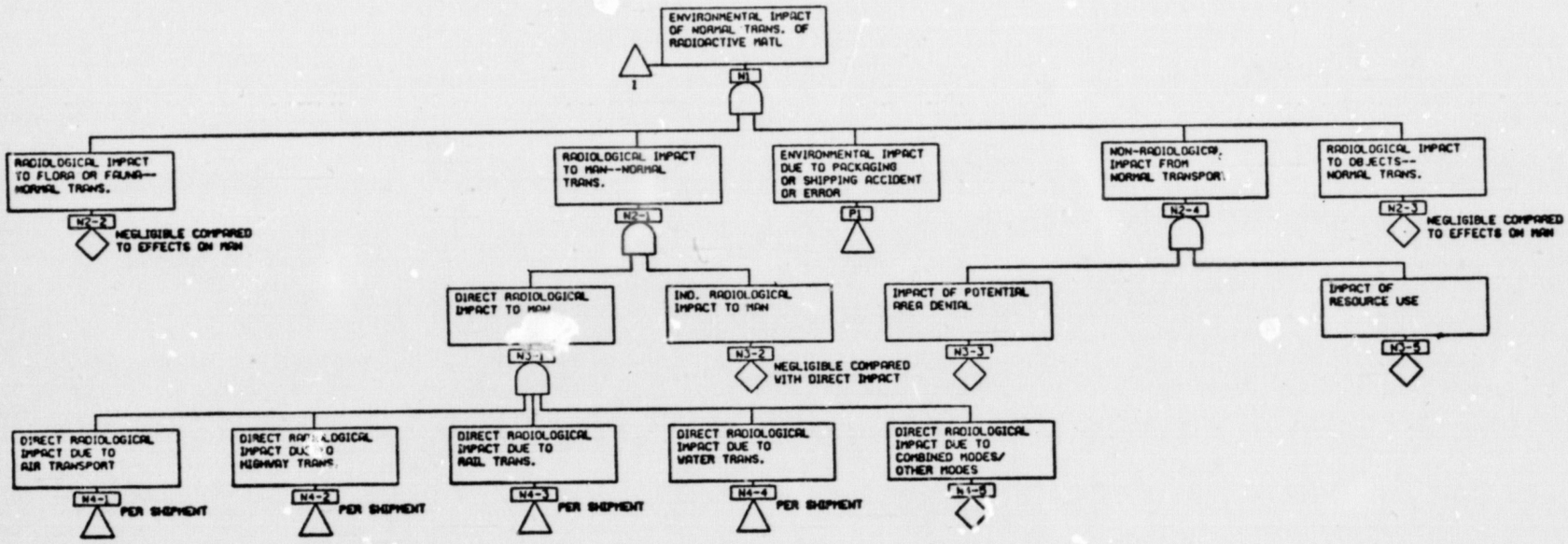


FIGURE IV-2. Logic Model for Normal Transport in all Modes

considered. These effects are judged to be very small in the normal transportation case. Event N3-2 is judged to be negligible since no credible mechanism exists for an indirect radiological effect, except through the food chain and by activation mechanisms. The food chain avenue is foreclosed in the normal case by package containment; radiation outside packages is sufficiently low that activation of structures surrounding man is unlikely. Exposures to casually-exposed life forms are so low as to present no significant impact.

Radiological Impact on Objects

The principal radiological impact on objects (N2-3) is to unexposed photographic films. Spacing regulations between radioactive material packages and film minimize this problem.

Radiological Impact on Man

The principal mechanism for producing environmental impact during normal transportation events is direct radiation to nearby persons from the radioactive material in the package. This mechanism is shown as event N3-1 on Figure IV-2. This event and those leading to it in normal transport are characterized as allowing no breach of packaging and no spread or leakage of the package contents. Only those radiations which can escape from the package, namely electromagnetic radiation and neutrons, produce an environmental effect. For conservatism, no shielding from buildings or vehicles is considered in this report.

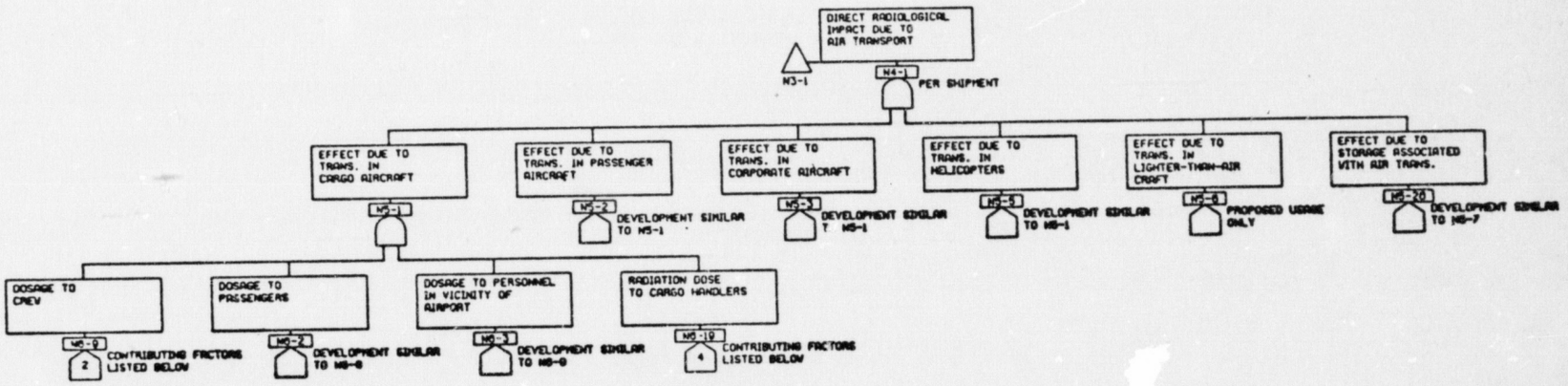
Because the radiation dose rate decreases rapidly with increased distance from the package, objects closest to a package receive the largest radiation dose rate. Thus, people who handle the package directly (such as loaders, dock workers, and baggage handlers) receive the highest dose rates. However, these exposures are for very short periods of time and generally do not result in appreciable doses. Specific consideration of the dose to handlers in all transport modes is addressed in Section G of this chapter.

Those who work in the vicinity of the package (but do not actually handle it) or who are transported with it, are subjected to a lower dose rate but for varying and longer lengths of time. By-standers along a travel route are farther from the package and are subjected to even lower dose rates, but the time of exposure depends on the characteristics of the transportation mode. The product of dose rate and exposure time summed for all exposed individuals is the principal indicator of the environmental impact to man. In the normal case the events producing this impact occur in tier 6 of Figure IV-3, for example, and are common to all modes and sub-modes of transport shown in tiers 4 and 5 on Figure IV-2 through IV-6.

For the purposes of considering only direct radiation hazards, the most important characteristic of a package containing radioactive material is the transportation index (TI defined in Chapter II). The radionuclide and the characteristics of the packaging material are of little importance in evaluating the impact in the normal case. However, these characteristics of the packaging and radioactive material may govern whether the material can be shipped by a given transport mode and may limit the total number of packages on a given vehicle.

Evaluation of the radiological impact of normal transportation requires data on radionuclides shipped, TI per shipment, transport mode used, distance shipped, routes used, populations exposed, and speed of shipment, to name the principal variables involved. Data relating to the materials and quantities shipped, transport mode, and distance traveled are given in Table IV-1 for the standard shipments shown in Chapter I. Other information used in the analysis of normal transport are shown in Appendix E together with the expression for population dose in which the parameters are used.

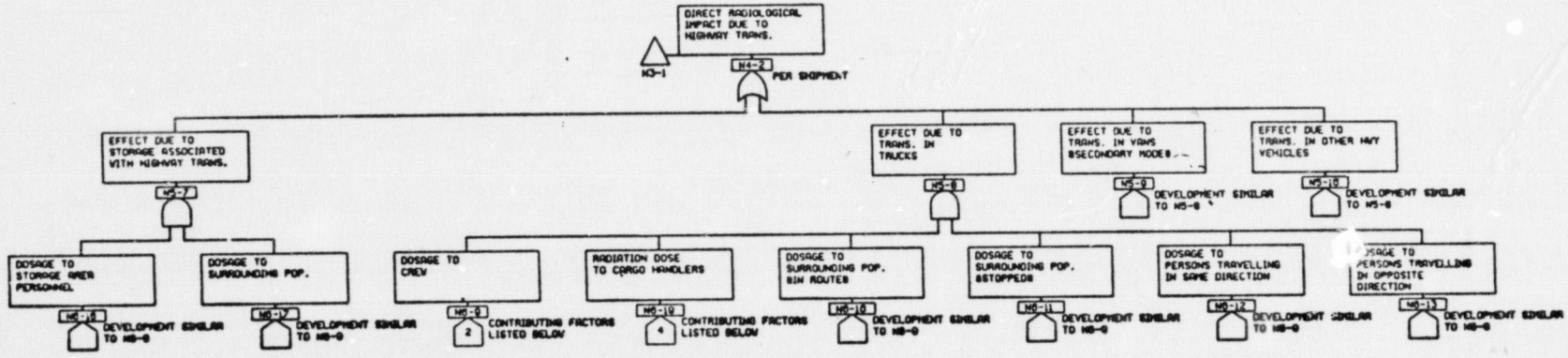
Various shipping modes have different characteristics with respect to speed, location of by-standers, carriage of passengers,



1. Number of crew aboard
2. Radiation level to crew
3. Radiological source
4. Distance from source to crew
5. Available shielding

1. Number of packages handled
2. Number of TI per package

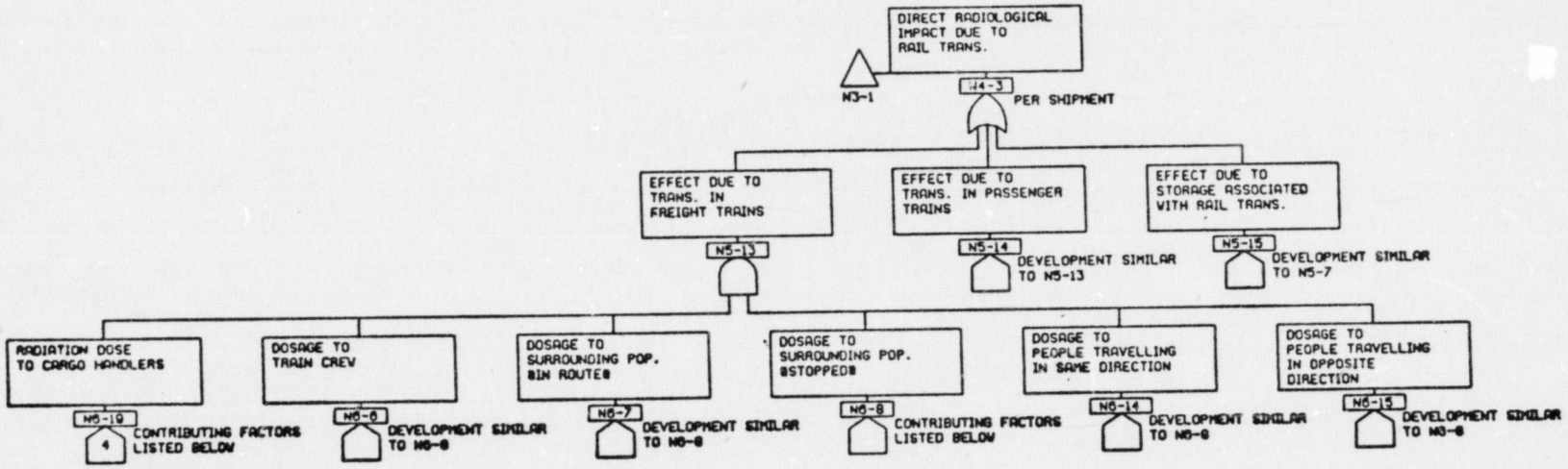
FIGURE IV-3. Logic Model for Air Transport Mode



1. Number of crewman aboard
2. Radiation level to crew
3. Radiolocal source
4. Distance from source to crew
5. Available shielding

1. Number of packages handled
2. Number of TI in package

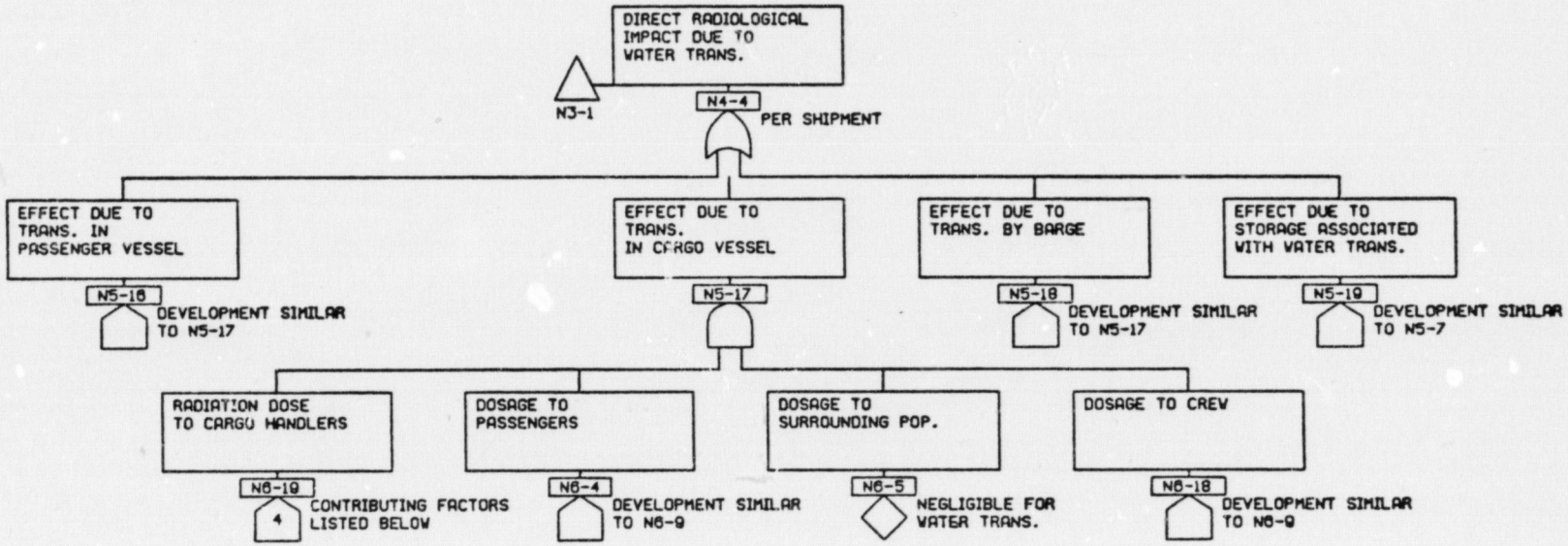
FIGURE IV-4. Logic Model for Highway Transport Mode



1. Number of packages handled
2. Number of TI per package

1. Exposable population
2. Radiation source level
3. Distance from source to population
4. Number of sources

FIGURE IV-5. Logic Model for Rail Transport Mode



1. Number of packages handled
2. Number of TI per package

FIGURE IV-6. Logic Model for Water Transport Mode

TABLE IV-1. Baseline Shipment Information

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.3E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO_2	3628.000	B	1	5.5E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBDATE
MO99 SMALL	.800	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	56.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+05	SOLUBLE LIQUID
RAPH. SMALL	.042	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.80E+04	3.80E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	6.37E+03	3.33E+04	3.33E+04	2.38E+04	0.	0.	2.38E+04	0.	0.
IR192 SOURC	6.80E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO_2	2.60E +02	0.	0.	1.12E+02	0.	0.	1.12E+02	0.	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.78E+04	1.64E+04	1.64E+04	1.64E+04	0.	0.	1.64E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH. SMALL	4.47E+03	2.33E+04	2.33E+04	1.67E+04	0.	0.	1.67E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	800	50	1000	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO_2	1200	0	0	1200	0	0	50	0	0
MO99 LARGE	250	0	0	1000	0	0	0	0	0
MO99 SMALL	800	50	1000	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH. SMALL	800	50	1000	1000	0	0	200	0	0

and other factors which affect exposure of people to radiation from shipments. For that reason each primary mode shown in Figure IV-2 (4th tier) will be considered separately when assessing environmental impact. For most primary modes there will frequently be a secondary transport mode associated with moving the package from the shipper to the primary mode terminal and from the end point terminal to the receiver. This secondary transport association with all modes is considered separately in the Section related to Truck, Light Truck and Delivery Vehicles (D.2-2).

D.1 Transport by Air

The generation of environmental effects from radioactive material transport by air is shown schematically in Figure IV-3. Discussion of the environmental impact will be divided into five subsections, relating to the principal transport mode: commercial air passenger service (N5-1), commercial air cargo service (N5-2), other fixed wing modes (N5-3) such as air taxi and corporate aircraft, helicopter (N5-5), and lighter-than-air craft (N5-6). The latter two are currently being discussed for possible use for certain specialized transport problems.

D.1-1 Transport by Passenger Aircraft

As indicated in an earlier section, shipment of radioactive materials in passenger aircraft is limited by statute[1] to those isotopes intended for either medical or research use. The environmental impact of transporting these materials has been covered in great detail by an FAA study[2] prior to a rule-making proceeding under consideration. The FAA study contains a very detailed description of the way radiation doses were estimated and how the total population dose (in person-rems) was calculated. That presentation will not be repeated here since the study is available to interested readers. The procedure used is shown schematically in tiers 6, 7, and 8 of Figure IV-3. The salient facts from the study are presented in Table IV-2.

TABLE IV-2

Population Dose and Individual Dose Estimates for Passenger Aircraft Shipments of Radiopharmaceuticals

	I*	II**
Total Passengers per Year	1.75×10^8	2.07×10^8
Exposed Passengers per Year	6×10^6	7×10^6
Number of Flights per Year	4.9×10^6	4.7×10^6
Total TI Shipped per Year	4.0×10^5	1.9×10^5
Population Doses $\left(\frac{\text{person-rem}}{\text{yr}}\right)$:		
Passengers	1400	870
Crew	1	1
Cabin Attendants	70	54
Individual Doses $\left(\frac{\text{mrem}}{\text{yr}}\right)$:		
Passenger	340 max. 60 avg. }	in most exposed group
Crew	10 max.	
Cabin Attendant	150 max. 30 avg.	

* Based on 1973 shipper survey[3], airline survey, and 1971 Airline Traffic Data

** Based on 1975 estimated shipping[2] and ALPA embargo limits

This table contains entries taken from the FAA study, as well as those from Reference 3, and information obtained directly from the National Transportation Safety Board (NTSB). The first column represents the dose estimate and other shipping information for a period in 1972-73 when the data were obtained. At that time there were some 4×10^5 radioactive material packages transported annually by passenger aircraft, and the total population exposure was estimated to be about 1470 person-rem annually (Table IV-2).

The second column is estimated dose and shipping data for early 1975 based on an informal industry survey and by use of the conversion factor derived by Barker, Hopkins and Tse[3] from exposure data and consideration of airline traffic information.

In the FAA study the dose values for passenger, crew, and cabin attendants shown in Table IV-2 were calculated using the following expression:

$$\text{Population Dose} = N_{P/F} \cdot N_F \cdot RTF \cdot K_{D/TI} \cdot TI \cdot L/v \times 10^{-3} \quad \text{person-rem/yr}$$

Here $N_{P/F}$ = number of people per flight

N_F = number of flights per year

RTF = radioactive material traffic factor, that is, the number of flights carrying radioactive material (RAM) divided by the total number of flights.

$K_{D/TI}$ = conversion factors between mean passenger dose rate and TI's aboard the flight (in millirem/hr/TI).

TI = the mean number of TI's shipped on a flight.

L = mean distance per flight (miles)

V = vehicle speed (mph).

This expression relies heavily on the empirical observation by Barker, Hopkins, and Tse[3] that mean exposure (for passengers primarily) was dependent directly on the TI contained in the aircraft hold and was only weakly dependent on geometry and other factors.

This expression can be used with mean values for the quantities involved to get a mean transport dose. By appropriate use of data for specific flights or specific airports, more detailed estimates of the variations in population dose can be obtained. For the purposes of calculating total population dose in this study, the product $N_F \cdot RTF$ was replaced by the number Ns of radioactive material shipments per year and L was redefined as the mean number of miles each shipment traveled. Thus the expression reduces to:

$$\text{Population Dose} = N_{P/F} \cdot D/TI \cdot N_S \cdot TI \cdot L/V \times 10^{-3} \left(\frac{\text{person-rem}}{\text{yr}}\right) \qquad (1)$$

D.1-1.1 Passenger Dose Commitment. As indicated in Table IV-1 only radiopharmaceuticals are considered to be transported by passenger aircraft. The materials considered and the parameters used in the calculation are shown in Table IV-3. Using these parameters in Equation 1 yields a passenger dose of 866 person-rem/ per year which compares favorably with dose estimates in Table IV-2. The discrepancy between the values is traceable to differences in number of passengers per flight, flight duration, and TI shipped.

D.1-1.2 Dose to Cabin Attendants. Calculation of the dose to cabin attendants was calculated in the same manner as the dose to passengers. The number of flight attendants exposed per flight was estimated to be four, and the dose conversion factor used was that suggested by Barker, 0.028 mrem/hr/TI. The latter factor is an average over the cabin length and acknowledges that the attendant moves throughout the cabin during the flight. The total person-rem accumulated by attendants over the course of a year was found to be 54 person-rem/year.

TABLE IV-3

Shipment Parameters for Calculation of Population Dose for the Passenger Air Shipment Mode

Transport Parameters:

Mean Speed (mph)	425
Passengers/Flight	60
Cabin Attendants/Flight	4
Crew/Flight	3
$K_{D/TI}$ (mrem/hr/TI) (passengers)	= 0.030
$K_{D/TI}$ (cabin attendants)	= 0.028
$K_{D/TI}$ (crew)	= 0.001
Stop Time (hrs)	= 1
Population Density at Stops (people/mi^2)	= 1000

Material Parameters:

Material	TI/Shipment	Distance/Shipment (miles)	Shipments/yr
TC 99 m	0.3	1000	3.8×10^4
I-131 (small)	2.4	1000	3.3×10^4
Mo-99 (small)	4.8	1000	1.7×10^4
RAPH (small)	1.5	1000	2.3×10^4

Total TI shipped/yr = 2.1×10^5

D.1-1.3 Dose to Crew. Crew members on passenger aircraft are often located away from radioactive materials packages. The common practice of storing packages in the rear baggage holds results in a cockpit dose rate which is very small. The positive effects of this practice are clear from the work done by Barker et al.[3] in defining radiation exposure to flight crews. In most cases radiation was undetectable when radioactive materials were stowed in the aft baggage compartment some 20 meters away. On two trips the dose rate was 0.1 mrem/hr while on 140 other trips the dose rate was undetectable. Using a dose rate of 0.001 mrem/hr/TI for crew (which is suggested by Barker's data) together with the assumption of three crew members and with the remaining parameters unchanged from those used in the passenger analysis, an estimate of 1 person-rem/yr to the crew is obtained.

D.1-1.4 Dose to By-Standers During Stops. During aircraft stops the population surrounding the aircraft both within and outside the terminal building is exposed to radiation from the radioactive material packages that the aircraft contains. This exposure is estimated using the following expression:

$$\text{By-stander Dose} = 3.1 \times 10^{7} \cdot P \cdot T \cdot TI \cdot N_S \text{ (person-rem/year)} \quad (2)$$

where

P = population density within one-half mile of the aircraft (people/mi^2)
T = average duration of stop (hours)
TI = the TI/shipment
N_S = number of shipments per year.

This expression is derived from a relation given in Reference 5. The details of its application are shown in Appendix E.

The actual population density used in this expression is difficult to estimate because of non-uniformity in the distribution between terminals and apron areas. Using the values given in Table IV-3, the population dose to by-standers during stops is estimated to be 64 person-rem/yr.

D.1-2 Transport by All Cargo Aircraft

Transport of radioactive materials by air cargo is more common now than during the 1973 shipping survey. Major radiopharmaceutical manufacturers and other radioactive material users and shippers have stated (during an informal survey) that the Air Line Pilot's Association embargo against radioactive material shipments on passenger aircraft had forced them to shift significant quantities of material to air cargo and package express airlines. Radioactive material shipments were shifted to truck where distances were short enough to make prompt delivery possible.

The amount of material that can be diverted to air cargo aircraft is limited since cargo flights are only about 0.2 percent of total air traffic.[4] In addition, there are only a limited number of airports that are large enough to support the freight handling facilities necessary for efficient loading and unloading of air freighters. Thus, the destinations of packages sent by air cargo are limited to a relatively few select terminal areas.

The principal environmental impact from normal transport of radioactive materials by cargo aircraft, as in the passenger aircraft case, results from the penetrating gamma and neutron radiation from radioactive material packages. In a cargo aircraft radioactive materials are required to be placed at least 7 feet from the crew compartment, but are usually placed at the farthest point from the crew compartment. Although the dose rate for crew exposure under the regulations could be as high as 0.3 mrem/hr/TI, the value for passenger flights, 0.001 mrem/hr/TI, was taken to be more realistic.

At the time of this report, two cargo carriers were operating under an FAA waiver which permitted carriage of up to 200 TI per aircraft on specific routes and for a specific time period. This increase in the allowable TI has the potential for increasing the exposure to individual members of the crew, but stowage requirements are used to minimize the dose rate in the crew area. Table IV-4 shows the standard shipments for the air cargo mode and the appropriate transport parameters for calculation.

D.1-2.1 Dose to Crew. Crew exposures were calculated using Equation 1 with the parameters listed in Table IV-4 and summed for all the material shipments considered. The value calculated was 1 person-rem to crew per year.

D.1-2.2 Dose to By-standers during Stops. By-stander dose from the air cargo mode was calculated for the time required to unload or add cargo to the freighter aircraft. Because freight operations usually occur in areas away from the main terminals the population density may be lower than that for the passenger air case, but the same population density is used for this calculation. Using Equation 2, the by-stander dose was estimated at 60 person-rem/year.

D.1-3 Transport by Other Fixed Wing Modes

The movement of radioactive materials by other fixed wing modes such as corporate aircraft is covered by the same general rules as those which govern cargo aircraft. An informal survey suggests that some materials do move by this mode, particularly in the oil well logging industry. The environmental impact is determined in essentially the same way as in the air cargo mode except that the aircraft are usually physically smaller than the typical cargo aircraft and therefore do not permit as large a spacing between the crew and radioactive packages.

TABLE IV-4

Shipment Parameters for Calculation of Population Dose for the Air Cargo Shipment Mode

Transport Parameters:

Mean Speed (mph)	425
Crew/Flight	3
$K_{D/TI}$ (crew) (mrem/hr/TI)	0.001
Stop time (hrs)	1
Population Density at Stops (people/mi^2)	1000

Material Parameters:

Material	TI/Shipment	Distance/Shipment	Shipments/Yr
I-131 (small)	2.4	1000	2.4×10^4
Ir-192 R.M.	4	1000	1.3×10^2
PuO_2	5	2000	1.3×10^2
Mo-99 (large)	3.6	1000	7.2×10^3
Mo-99 (small)	4.8	1000	1.6×10^4
I-131 (large)	1.6	1000	1×10^3
RAPH (large)	1.7	1000	2.7×10^3
RAPH (small)	1.5	1000	1.7×10^4

Total TI shipped/yr = 2×10^5

The quantity of material transported by other fixed wing modes is estimated to be no more than one percent of that transported by all cargo aircraft. However, the dose rates to crew members are expected to be greater than for cargo aircraft because of the aircraft size, and are taken to be four times larger. The result is an estimated total annual dose from this mode of 2 person-rem/year. This dose is negligible compared to the values calculated for other air transport modes.

D.1-4 Transport by Helicopter

Helicopter as a mode of transport for radioactive material is not widely used. No commercial use by common carrier was discovered as a result of conversations with industry representatives. However, use of corporate helicopters for transporting radioactive material was found to have occurred. One common usage is in the transfer of well logging sources to offshore drilling rigs operated by oil companies. The actual extent of such transfers is unknown, but a thousand such transfers per year is considered to be typical. For a two-man crew, a one-hour flight time, and a dose rate of 2 mrem/hr at occupied positions, a possible dose commitment of about 4 person-rem per year is obtained. This is a comparatively small population exposure and a negligible fraction of the total population dose for air transport.

Additional usage of the helicopter as a secondary mode is being discussed for transport of Special Nuclear Material (SNM), that is between a terminal (either air, truck, or ship) and the user/sender. However, this use is only a possibility and can only be discussed in those terms. The impact of such use is evaluated in Chapter VI.

D.1-5 Transport by Lighter-Than-Air Vehicle (LTA)

As stated in the previous section relating to helicopters, LTA is also being discussed as a possible transport mode for SNM

because of possible security and safety advantages over other primary and secondary modes. There is no current use of LTA vehicles in radioactive material transport, but contemplated use for SNM shipments would result in an annual population dose not exceeding one percent of that resulting from all transport by air-cargo, or 2 person-rem/year, a negligible dose.

D.1-6 Storage Associated with the Air Transport Mode

The radioactive material package may be considered to be in storage between being offered for shipment and being placed aboard an aircraft and again after removal from the aircraft but before transfer to a secondary mode vehicle for delivery to its final destination. Storage areas are typically on or near the airport grounds and are part of the airline freight handling facilities where people may be working in the area surrounding the package. Terminals visited during the course of this study had a specific location set aside for such packages, but the area was not well isolated from the general work area. If it is assumed that the uniform population density surrounding the package is approximately 1000 people per mi^2 and that the package is in such an area for a total of two hours before, during (aircraft change), and after a flight, then the population dose as estimated using Equation 2 is 479 person-rem/year for the combination of shipments shown in Tables IV-3 and IV-4.

The principal component of this exposure is that related to radiopharmaceuticals having relatively short half lives which must be moved as promptly as possible. The two-hour exposure time is likely to be appropriate for this type of shipment.

D.2 Surface Transport by Motor Vehicle

With an estimated 60 percent of all radioactive material packages moving by air, the remaining packages, an estimated 240,000, are divided between the land (truck and rail) and water transportation modes. The exact split of this traffic between

land and water modes is largely unknown at this time. Completion of the 1975 shipper survey should provide a reasonably good estimate of the total movements of materials in the long distance trucking industry. Some of these truck shipments result from a shift of 15 percent of the total radioactive material traffic away from the air mode as a result of the ALPA embargo and the Transportation Safety Act of 1974. These shipments were probably shifted from air to the next fastest and direct mode, truck. While a number of truck shipments are likely to be dominated by radiopharmaceuticals, the weight capabilities of trucks mean that a substanial fraction of those radioactive materials requiring massive shielding also can be shipped by truck. These latter shipments are relatively few in number and are associated with fuel cycle wastes, irradiator sources, and other high specific activity or large quantity sources.

An additional source of truck traffic is secondary mode transportation between a common carrier's terminals and shippers or receivers. It is assumed that almost 100 percent of the packages not carried by trucks in the primary mode (that is, not loaded directly into a long distance hauler for direct delivery) are carried in a secondary mode by trucks, light duty vans, or automobile. In general, this mode of travel is likely to be associated with slower speeds and larger population densities than the inter-city truck routes. Therefore, the total volume of packages moved in secondary transport will be high but total miles traveled will be low. This facet of the surface transportation of radioactive material is addressed in section D.2-2.

D.2-1 Transport In Trucks

The principal mechanism for producing environmental impact from truck transport of radioactive materials is by direct radiation to handlers, crew, and by-standers. Here, in contrast to the passenger aircraft case, there are no passengers to be exposed

to the radiation, but the public is exposed during passage of the vehicle. While in most cases people are exposed for a relatively short duration, the number of persons who can be exposed may become very large during a trip of considerable distance. An additional contrast with air transport is posed by the fact that people are also exposed while a truck is stopped for meals, crew rest, repair, and refueling. Because access of these people to the area around the vehicle is not limited as in the case of air shipment, the potential for exposure is higher.

D.2-1.1 Calculations of Population Exposures. To estimate the population dose from shipments by any land based mode, it is necessary to calculate the radiation field surrounding the vehicle and the dose received by persons moving and stationary in this field. This sort of calculation has been carried out in Appendix E using results from Reference 5.

D.2-1.2 Dosage to Truck Crew. Maximum dose rates for motor carrier drivers are established by package separation distance, but are considered to be no more than 2 mrem/hr for any portion of the vehicle continuously occupied by people. Since the crew is assumed to be in the cab only during periods of actual travel, the hours of exposure are approximately those during which the shipment is moving. Thus, the dose received by the truck crew is given by:

$$\text{Dose to Crew} = 10^{-3} \cdot N_c \cdot L/V \cdot D_c \cdot TI \cdot N_S \cdot K_{D/TI} \text{ (person-rem/yr)}$$

where

N_c = Average crew per truck

L = Miles/shipment travelled

V = Mean shipment speed (miles per hour)

D_c = Dose rate in crew compartment mrem/hr (2 mrem/hr max)

$K_{D/TI}$ = TI to dose rate conversion (mrem/hr/TI - such that $K_{D/TI}$* TI $\leq$ 2 mrem/hr)

N_s = Number of shipments per year

TI = Mean TI per shipment

When $K_{D/TI}$ is evaluated for shipment in interstate trucks, a dose rate of approximately 0.15 mrem/hr/TI is estimated from Figure E-1 in Appendix E for a distance of 10 feet between the cab and the package being transported. Since this is likely to be a minimum distance between package and crew, the dose to truck crews calculated in this manner is a maximum. At a distance of 30 feet the dose rate is reduced by a factor of 8 to 0.02 mrem/hr/TI.

The remaining parameters for evaluation of the above expression are contained in Table IV-5. The total crew dose is obtained by summing over the materials shipped and the speed-time combinations. Using two dose rate values given, the resulting exposure to a two-man crew is estimated to be as large as 705 or as small as 60 person-rem per year.

D.2-1.3 Dose to Population Surrounding the Moving Vehicle. The estimation of the population dose from the moving vehicle is composed of two principal components: that resulting from the exposure of other vehicles occupying the transport link (on-link) and that to surrounding population (off-link).

In the former case, the dose is divided between that to oncoming and following traffic. The combined dose to those groups is given by Equation 3, which is derived in Appendix E.

$$\text{On-Link Population Dose} = 2.5 \times 10^{-7} \frac{KNS}{V_T V_S} \cdot D_m \cdot L \cdot TI \cdot N_s \left(\frac{\text{person-rem}}{\text{year}}\right) \quad (3)$$

Here K = Traffic density factor ≈ 2 daytime ≈ 4 rush hour

N = Daily traffic counts on roadway (vehicle/day)

S = Number of people per vehicle

V_T = Traffic speed (miles per hour)

V_S = Shipment speed (miles per hour)

D_m = Mean dose rate to following and oncoming vehicles (mrem/hr)
= 0.14 mrem/hr for 2-lane highway
= 0.09 mrem/hr for 4-lane highway
= 0.07 mrem/hr for 4-lane divided highway

TABLE IV-5

Shipment Parameters for Calculation of Population Dose for the Truck Transport Mode

Transport Parameters:	High Population Areas	Medium Population Areas	Low Population Areas
Speed (miles per hour)	15	25	55
Distribution of Travel Distance	0.05	0.05	0.9
Population Density $\left(\frac{\text{persons}}{\text{mi}^2}\right)$	10,350	1035	104
Duration of Stops (hours)	1	5	2
Traffic Distribution			
Fraction in Rush Hour	0.08	0.08	0.08
Fraction in Non-Rush Hour	0.92	0.92	0.92
Roadway Distribution			
Fraction 2 Lane	0.10	0.10	0.10
Fraction 4 Lane	0.10	0.10	0.10
Fraction Freeway	0.80	0.80	0.80

Material Parameters:	TI/shipment	Distance/shipment	Shipments/yr
I-131 (small)	2.4	600	6.4×10^3
Ir-192 Sources	2	1000	6.6×10^3
PuO_2	5	2000	2.4×10^2
Mo-99 (large)	3.6	250	7.2×10^3
Mo-99 (small)	4.8	600	1.8×10^4
SFFP	100	1000	5.4×10^1
RAPH (small)	1.5	600	4.5×10^3

Total TI shipped = 1.5×10^5

L = Miles travelled/shipment

TI = TI/shipment

N_S = Number of shipments/year

Consideration of the many possible traffic patterns makes realistic evaluation of this population dose a complex problem. The traffic mix indicated in Table IV-5 consisting of 80 percent freeway and 20 percent urban and suburban streets with 8 percent rush hour and 92 percent non-rush hour travel, when summed over all material shipments, yields a population dose of 16 person-rem/year.

The second component of the dose to population surrounding the moving vehicle is that to persons living and working in areas surrounding the transport link. The dose to these groups is given by Equation 4 which also is derived in Appendix E.

$$\text{Off-Link Population Dose} = 3.1 \times 10^{-7} \cdot P \cdot L \cdot N_s \cdot TI/V_s \qquad (4)$$

The quantity P is the population density (persons/mi^2) surrounding the transport link, and other factors are as defined previously. Using the data given in Table IV-5 and summing results over components of the travel and materials shipped yields approximately 1042 person-rem/yr for this component of the population dose.

Neither off-link nor on-link results account for the effects of shielding which would act to mitigate the population dose. Shielding is likely to be most effective in cities where buildings are constructed from relatively good radiation absorbers, such as concrete and steel, and in hilly terrain where topographic features provide shielding. If such shielding effectively limits the area irradiated to 300 feet on either side of the roadway, the off-link population dose would be decreased by a factor of 2.

D.2-1.4 Dose to Population While Vehicle is Stopped. An estimate of the population dose received while the vehicle is stopped is obtained by assuming that half the travel time is spent at rest. Some states do not allow shipment of radioactive

materials at night, and the need for fuel and food takes additional time away from the trip. Actual travel is assumed to consume approximately 8 hours per day. The assumptions shown in Table IV-5 regarding the length of stops in the various populated areas shown result from the observations that fuel stops and rest areas are often in suburban areas or in areas which have higher than the local average population. The expression used for calculation of the population dose for a given stop time, T, per shipment is given by a variant of Equation 2 in which the product of P and T is weighted as shown in Table IV-5. Evaluation of the expression yields 721 person-rem/yr from rest stops involving trucks carrying radioactive materials. Again, the effects of shielding by buildings and terrain might reduce this value by a factor of 2.

D.2-1.5 Dose Resulting from In-Transit Storage. At the beginning and end of the transport cycle and at intermediate terminals, radioactive material packages may be stored temporarily while awaiting a truck which is proceeding to the final destination. The potential exists, therefore, for irradiation of truck terminal employees and surrounding population during these periods of temporary storage. The population density in the area exposed is taken as 1000 person/mi^2 (similar to the air shipment storage calculation). The population dose is calculated using Equation 2 for the materials listed in Table IV-5 and for a storage time of two hours. The resulting population dose for in transit storage is found to be 183 person-rem/yr.

D.2-2 Truck, Light Truck and Delivery Vehicles

This transport mode makes up the principal part of secondary transport. All radioactive materials that are shipped by air, almost all that is trucked from city to city, almost all that goes by rail, and almost all that goes by water are handled by light truck and private and company cars in a secondary mode. Most driving is to freight terminals associated with cities, and thus the population densities are relatively high and the speeds achieved are relatively low.

Using the calculational structure developed for the truck mode with the material and transport parameters shown in Table IV-6, the following estimates of population dose to the indicated groups are calculated:

1. dose to crew (1 person) = 14 person-rem/yr.
2. dose to surrounding population (on-link) = 134 person-rem/yr.
3. dose to surrounding population (off-link) = 3866 person-rem/yr.
4. dose to surrounding population (stopped) = 580 person-rem/yr.
5. dose to surrounding population (intransit storage) = 448 person-rem/yr.

The total population dose is estimated to be approximately 5042 person-rem/year.

D.3 Rail Transport

The methods used for calculating the impact of transport by rail are similar to that for truck transport because of similarities in route structure and services areas. Both rail rights-of-way and railroads pass through populated areas. The major differences between truck and train are in the speed of transport (train is generally slower) and the proximity of population exposed on the rail link. Although the speed of a freight train while moving through the country side is reasonably fast, the need to enter sidings occasionally to allow faster trains to pass and to pick up and drop off cars reduces the mean speed considerably. This results in a longer time for exposure of the public to radiation. Where passenger trains pass or are passed, a population dose is incurred in a manner analogous to that received by other vehicles using the highway in the trucking mode.

D.3-1 Transport by Freight Trains

Because of slowness and special capability for handling massive loads, the principal materials shipped by railroad are expected to have long half-lives or require special shielding such

TABLE IV-6

Shipment Parameters for Calculation of Population Dose for the Delivery Vehicle Transport Mode

Transport Parameters:	High Population Areas	Medium Population Areas
Speed	15	25
Distribution of Travel Distance	0.4	0.6
Population Density $\left(\frac{\text{people}}{\text{mi}^2}\right)$	10350	1035
Stop Duration (hr)	0.5	0
Traffic Distribution		
Fraction in Non-Rush Hour	0.92	0.92
Fraction in Rush Hour	0.08	0.08
Roadway Distribution		
Fraction on City Streets	0.65	0.65
Fraction on 2 lane	0.1	0.1
Fraction on 4 lane	0.05	0.05
Fraction on freeway	0.2	0.2

Material Parameters:	TI/shpt.	Distance/shpt.	Shipments/yr.
Tc-99	0.3	50	3.8×10^4
I-131 (small)	2.4	200	2.4×10^4
I-131 (small)	2.4	50	3.3×10^4
Ir-192 R.M.	4	50	1.3×10^2
PuO_2	5	50	1.1×10^2
Mo-99 (small)	4.8	200	1.6×10^4
Mo-99 (small)	4.8	50	1.6×10^4
SFFP	100	50	3.3×10^2
RAPH (small)	1.5	200	1.7×10^4
RAPH (small)	1.5	50	2.3×10^4

Total TI Shipped = 4.0×10^5

as spent fuel. While no specific information is at hand to suggest that radioactive materials are not shipped on passenger trains, no evidence of such use was discovered in an informal survey of the industry.

D.3-1.1 Exposure of Train Crew. In the average freight train there are approximately 60 cars. As a result, the proximity of train crew to a car carrying radioactive material is difficult to quantify except on a statistical basis. While the train is in motion, a brakeman or flagman in a caboose may be as close as 10 feet or as far as several hundred feet from a radioactive shipment. If the latter condition occurs, a great deal of intervening cargo will act to shield the crew car. Similar arguments can be made for the engine crew so long as there is only one shipment per train. If there is only a single cargo car making up the train, the engine crew and caboose crew will experience similar dose rates. The calculation of the dose received by the crew proceeds in a manner similar to that used for trucks. The expression (Equation 1, restated):

$$\text{Crew Dose} = 10^{-3}\ N_C \cdot L/V \cdot D_C \cdot N_S$$

must be evaluated using the shipment data appearing in Table IV-7. A value of 0.1 mrem/hr for D_C was obtained from Figure E-1 of Appendix E and was based on a separation distance of 120 feet between any space occupied by crew and the radioactive material shipment. Evaluating the expression shown with the data shown in Table IV-7, yields a crew exposure estimate of 7 person-rem/yr.

D.3-1.2 Exposure of Surrounding Population. The exposure estimate to surroundings is composed of that to those on the transport link and to those surrounding the link. Those exposed on the transport link are passengers on trains or freight train crews who pass or who are passed by a train carrying radioactive materials. Equation 3 for the on-link data is:

TABLE IV-7

Shipment Parameters for Calculation of Population Dose for the Rail Mode

Transport Parameters:	High Population Areas	Medium Population Areas	Low Population Areas
Speed (mph)	15	45	60
Distribution of Travel Distance	0.05	0.05	0.9
Population Density $\left(\frac{\text{people}}{\text{mi}^2}\right)$	10350	1035	104
Stop Duration (hrs)	0	0	6
Passenger Trains (trains/day)	30	10	1
Number of Crew-5 (2 engineers and 3 trainmen)			

Material Parameters:	Radiation	Distance Shipped	Shpt's/yr.
Spent Fuel	200 mr/hr at car's surface or an effective TI of 100 (see Appendix E)	1000	326

$$\text{On-Link Population Dose} = 2.5 \times 10^{-7} \frac{KNS}{V_T V_S} D_m \cdot L \cdot TI \cdot N_s$$

For application in the railroad context, K is taken to be unity and D_m has the value for 2-lane roads (0.14 mrem/hr). The remaining parameters are taken from Table IV-7 to yield a dose smaller than 1 person-rem/year to on-link population.

Using Equation 2 and the data given in Table IV-7, and summing over the population zones, a value of 366 person-rem/yr. to the surrounding off-link population is obtained.

D.3-1.3 Exposure to Population During Stops. As indicated earlier, stops at rail sidings resulting from the need to let faster trains go by or to pick up additional cars are likely to be frequent. If it is assumed that the train is stopped 6 hours each day and those stops occur predominately in low population density zones, the population dose (using Equation 2) is estimated to be 6 person-rem/yr from this source.

D.3-2 Storage Associated with Rail Transport

Storage associated with rail transport is expected to be non-existent or, at most, a minor influence on the overall environmental impact. For transport of spent fuel and similar consignments which occupy a single car, storage might be considered to be the time spent in rail yards waiting to be included in a train moving toward the final destination. In such a location exposed population densities are assumed to be 100 people/mi^2. If the time spent in such areas is 2 hours per shipment, the population dose computed by Equation 2 is 39 person-rem/year.

As a result of freight forwarder activities there may be freight car shipments of other radioactive materials which do not appear in the standard shipments for the rail mode. No allowance for such freight shipments is made in this report;

however, the impact would be proportional to the TI rating of the packages shipped in the cars.

D.4 Transport by Water

As a result of a paucity of information relating to the actual quantities of materials shipped by water, the movement of radioactive material by water will be given only limited consideration in this document. If the capabilities of water transport are examined with respect to the needs of the radioactive material shipping industry, it is clear that some materials might well be expected to appear in water-transport modes. Historically, water modes have been involved with shipments of material that were massive or bulky or which did not require exceptionally fast travel. This sort of capability fits with the need to transport spent and new fuel, heavily shielded material, or long half-life isotopes.

D.4-1 Transport by Barge

It is suspected that barge may be a method for transport of new and spent fuel to reactors and reprocessors located on appropriate waterways. The extent to which this occurs is unknown, but total shipments are expected to be fewer than 10. With relatively few people exposed at distances of 100 feet or more during movement and a few at each terminal, population exposure is expected to be negligible.

D.4-2 Transport by Ship

For the overseas export-import trade in radioactive materials there are only two transport modes available, air and ship. It is expected that relatively light weight (less than a few tons) or short half-life materials will move by air, while more massive and longer half-life materials will move by ship. Shipments of spent fuel moving from off-continent reactors to reprocessing or storage facilities will most certainly arrive by ship. At least

one such shipment occurred in 1975. In addition any effective ban on air transport of plutonium as is currently in effect must necessarily mean a shift of plutonium import-export traffic to the water mode (one such shipment occurred late in 1975).

The annual number of radioactive material shipments by ship is estimated to be 1 percent of those by both truck and rail. However, the number of crew and passengers on a vessel is estimated to be a factor of 10 larger than those for land modes. Based upon these factors, the annual dose from spent fuel and plutonium transport by ship is estimated to be 3 person-rem/yr., a negligible amount.

E. Non-Radiological Impacts on the Environment

The non-radiological impacts from transporting radioactive materials are divided into 2 principal areas; area denial and resource use (see Figure IV-2).

E.1 Area Denial

Shipment or storage of radioactive material imply the existence of areas in proximity to the material which are more or less unusable by man. By use of shielding and remote storage, however, these effects can be mitigated. Remote storage shifts the area denied to a place which may be less valuable or useful, and use of shielding substitutes use of a resource (shielding material) in exchange for use of the area previously denied.

To the extent that these exclusion or exclusive use areas would otherwise be used or subjected to more intense use, they represent some aspects of an environmental effect. The requirement for more space in a terminal facility for example, and the use of more land, money, and resources in constructing the space represent an environmental impact. The magnitude of this effect is likely to be small compared to the basic costs of being in the transportation business.

E.2 Resource Use

The primary resource use associated with radioactive material transport results from the commitment of shielding material for construction of packages and in the use of energy to move the transport vehicle. The shipment of radioactive material requires shielding of individual packages to permit the proximity of packages to people and photographic materials during the transport phase. The construction of these packages requires commitment of natural resources in a manner which may or may not permit recycling and reuse. The principal materials for shielding are lead and depleted uranium. The quantities committed at any one time to use as shielding in transportation packaging is estimated to be 1000 tons of lead and 200 tons of depleted uranium.

Reuse of lead shielding material by return of used packages to the shipper is accomplished (by interview with one radiopharmaceutical shipper) about 50 percent of the time. In the remaining cases the disposition of the material is unknown, but it may be assumed that a significant recycling effort takes place. This assumption is based largely on the fact that the radioactive material packages are received by people who are licensed to possess radioactive materials and appreciate the value of reusing the shielding material either directly or by recasting into a usable form. In addition, industrial and commercial users often have an active salvage operation for metals of all kinds. Thus, one might well expect no more than 20 percent loss in lead shielding material per year. A significant fraction of this material will be sent to refuse disposal areas. The environmental impacts of this loss are the energy and resources necessary to replace the unreturned material and the presence of lead in an uncontrolled environment. The fact that the lead required, except that for complete replacement of all transport shielding, is a small increment of that produced nationally suggests that the influence of this environmental impact is minor.

Other materials such as wood, steel, fiberboard, and plastic are also used in the construction of packaging used to transport radioactive materials. Since radioactive materials constitute only a very small percentage of the total amount of goods transported in similar packages, the use of these resources for their transport is considered negligible.

The second area of resource use is in the operation of the transportation industry itself. To transfer material from point A to B requires the commitment of men, money and resources to the job. To the extent that radioactive material shipments are a fraction of the total quantity of material transported, resource use might be prorated and charged to radioactive transport. However, such packages represent a trivial (10^{-4}) fraction of the total transportation picture and their removal from the transport industry is expected to have much less than a proportional, perhaps negligible, effect on decreasing the resource use of the industry.

A somewhat different picture emerges, however, when a shipment cannot be handled routinely within the existing transportation system. If, because of excessive bulk, mass, radioactivity, regulation, or work rules, a shipment must be handled as the sole cargo for transport between two locations, the resource use and environmental impact committed to that shipment can be identified with and charged to the transportation of radioactive materials. Such environmental impact items as fuel use, noise, pollution, and accidental injuries and deaths can be associated with such activities. It is expected that most sole-use operations occur for shipment of spent fuel for military and civilian reactors and for movement of large irradiator sources. Raw materials to feed the nuclear fuel cycle are also usually carried on sole-use vehicles because of their bulk rather than any consideration of their radioactive properties. Because the number of shipments of these types is so small, (see Chapter I), the impact is expected to be negligible.

F. Abnormal Transport Occurrences

In each mode of transport there is a class of incidents which can produce additional exposure of people to radiation and radioactive contamination. These incidents are considered here as a component of normal transportation because they do not involve an accident which causes damage to the shipping vehicle.

Considered in this context are events which may compromise package integrity such as dropping from a height, crushing under a truck, or skewering by a fork truck. Other "abnormal-normal" occurrences relating to packing procedures are failure to pack the radioactive materials properly, labeling packages with an incorrect TI rating (either too large or too small), failure to close seals properly, or incorrectly shielded radioactive sources. Similarly, package loss is an abnormal occurrence which may compromise the safe transport of radioactive materials. The hazards from each of these errors and occurrences are readily obvious in that they do produce the possibility for excess radiation to handlers and to the general public. The logic model for analysis of these aspects of normal transportation is shown in Figure IV-8.

Incidents which occur in transportation and which are suspected to have produced a release of radioactive material must be reported to the Department of Transportation (DOT) and the incident is investigated completely. A list of 98 reported incidents involving radioactive cargos was obtained from the DOT which covered the years 1971, 1972, 1973, and 1974. Of these 98 reports, 61 were received in 1974, and 1975 reporting rates are about 12 to 15 per month according to DOT record keepers. The 98 incidents are summarized in Appendix C in a complete list obtained from DOT. Of the 61 for 1974 and the 15 per month in 1975, fewer than 10 percent involved an actual

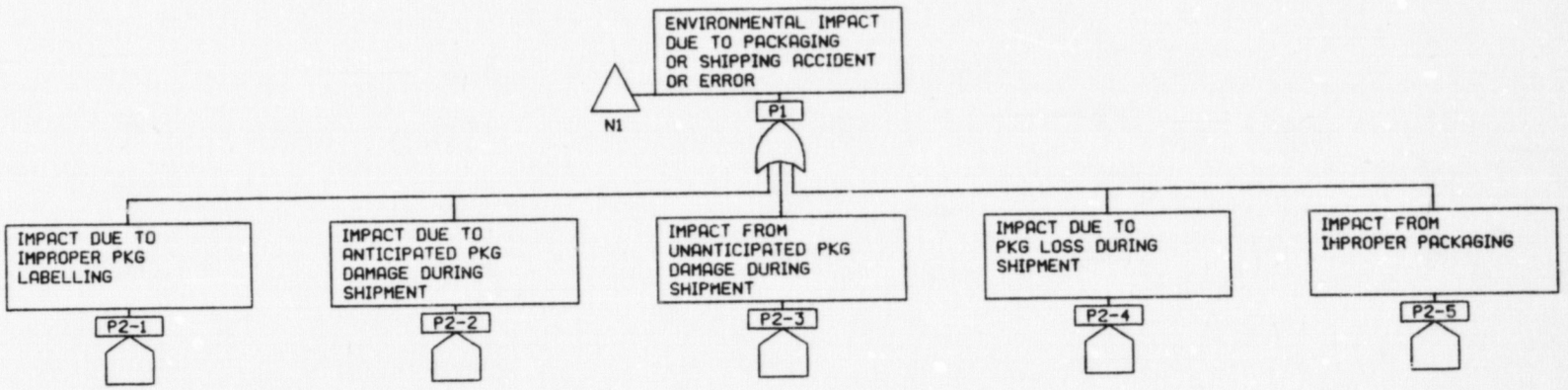


FIGURE IV-7. Logic Model for Analysis of Abnormal Packaging

release of radioactive material, but the reported incidents suggest that a certain extra risk is incurred over and above the exposures attained during the normal transport process.

F.1 Improper Labeling of Packages

One particular abnormal occurrence is mislabeling. Where the external radiation is less than that shown on the label by the TI, there would be no additional radiation exposure to the public, but shipment may be delayed because a transport vehicle has its full complement of TI's or because extra handling restrictions may require a larger commitment of resources in the shipment process. In the opposite case, there may be additional radiation exposure to the public, to handlers, and to others exposed to radiation from the package.

How mislabeling occurs is problematical, but two possible reasons seem most likely: errors in determining what TI value to use on the label and premature release of a package for shipment.

Premature release of a package for shipment is a problem with short half-life materials because the decay that occurs between labeling and actual commencement of shipping must be factored into the labeling process. If the time lag is underestimated consistently, an extra hazard is incurred by the public and the industry.

Measurements of package TI's in 1973 showed a significant number had more TI's than stated on the label.[6] To combat this problem, FAA has proposed that every package offered to the airlines be monitored before it is accepted for shipment. This is a procedure which can catch mistakes before the problem is spread through a large number of people.

F.2 Damage During Shipment (Anticipated)

The regulations which govern transportation and the standards to which packaging materials are designed suggest that the damage which is routinely incurred during shipment has been anticipated. The drop, water immersion, and crush standards, together with the absorbent packing required on liquid shipments are based upon experience in the shipping industry and are intended to protect against a reasonable range of normal handling environments. Thus, no significant additional exposure of the public is expected.

F.3 Damage During Shipment (Unanticipated)

While the packaging standards guard against release resulting from a reasonable range of normal environments, the occurrence in a four year period of 98 reported incidents involving radioactive material packages indicates that events which cause release can happen in the course of normal transport. The principal source of such incidents, as derived from normal industry surveys and the incident reports, is crushing under massive packages or pallets, puncture by trucks, or being crushed by loading machines or by the transport vehicles themselves. If one accepts the figures that in one year 61 incidents involving radioactive material packages occurred for 5×10^5 shipped, less than 0.02 percent of the packages are involved and only 0.002 percent actually involve a release.

Most radioactive materials are shipped in Type A packages which are designed only to withstand normal conditions of transportation. The quantities of material released in package damaging incidents are expected to be on the order of 10^{-3} of the package content. With this release fraction for Type A quantities of a radionuclide, and assuming that 10^{-3} of the material released is inhaled, ingested or absorbed an individual dose of about 0.5 rem/yr is expected. (This dose rate and release fraction are the basis of the Type A

quantity specification for each material.) Since most handling accidents are likely to occur in terminal areas, fewer than 10 people are likely to be exposed and the population exposure received per accident is unlikely to be greater than about 5 person-rem/year. At the current rate of 180 incidents a year with 10 percent involving a release, the expected population dose is expected to be less than 100 person-rem/yr from this source.

F.4 Impact Resulting from Package Loss

The principal impact resulting from package loss is irradiation of people in the vicinity of the package who are unaware of its presence or contents. To achieve such a result requires (1) a package to be separated from its radioactive labels if in the transport cycle, or (2) to be dropped off a vehicle in such a way that it remains hidden or is separated from its labeling. Either scenario is potentially serious if shielding is lost. The second is especially serious if a long half-life nuclide is involved which allows large numbers of person-rem to be accumulated.

An estimate of the dose accumulated can be made using the following variant of Equation 2.

$$\text{Population Dose} = 3.1 \times 10^{-7} P \left(\frac{t_{\frac{1}{2}}}{0.693}\right)\left|1 - e^{\frac{-.693T}{t_{\frac{1}{2}}}}\right| \cdot TI. \quad \text{(person-rem)}$$

where
- P = population density (persons/mi^2)
- $t_{\frac{1}{2}}$ = nuclide half-life in years
- T = time exposed in years
- TI = package TI or exposure rate (mrem/hr) at 3 feet

If P is 1000 persons/mi^2, typical of suburban areas, where the presence of a package might not be quickly detected, and the isotope is I-131 with an 8 day half-life, the maximum population

dose received from a 1.0 TI package lost or mislaid is 8×10^{-7} person-rem.

Standards for Type A packages are such that shielding will be maintained during a limited period of exposure to the elements. Even if complete loss of shielding occurred, the limits on Type A quantities are such that an exposure of no more than 1 rem/hour can occur at a distance of 10 feet. If the incident occurred in an area with a population density of 1000 persons/mi^2, population dose will accumulate at a rate of 9.3×10^{-3} person-rem/day in the absence of shielding by buildings and terrain.

The time to detect a lost package is likely to be comparable to the shipment time which ranges from a few hours to a few days. A high dose rate makes a search easier once a package loss is suspected. If the time to search and find the package is approximately 7 days, the maximum expected population dose per loss is of the order of 0.05 person-rem. Records indicate an average of 5 losses per year over the last 9 years. By the reasoning indicated above this would result in an average population exposure of no more than 0.25 person-rem/yr.

F.5 Impact From Improper Packaging

Improper packaging presents several possible hazards: inadequate shielding implies excessive dose rates, inadequate packaging implies releases, and incorrect installation of a source implies subsequent high exposure rates. Ordinarily, use of improper packaging or installation should be detected when the TI is determined prior to shipment.

G. Exposure of Handlers

Handlers of radioactive material packages receive the highest dose rate of any population group exposed to the radiation from packages but, because of relatively short exposure times, they

receive relatively small doses. A recent study[7] indicated that the average dose received was 2.5×10^{-4} person-rem/handling/TI.

The total population dose was estimated for each of the shipment scenarios using the number of handlings, the TI shipped, and the number of packages in each case. The total handler exposure was estimated to be 581 person-rem per year.

For an individual cargo handler to be exposed to 500 mrem in one year, he must handle a number of radioactive material packages such that the cumulative TI of those packages exceeds 2000. Radioactive material packages in this number are shipped only through the five airports which serve the principal radiopharmaceutical companies. With 190,000 TI/yr being shipped by air (see Table IV-2) and divided among 5 major airports, one airport may handle 40,000 TI/yr. If only 1/5 of that total goes to one airline this amounts to 8,000 TI/year/airline. If one person regularly receives shipments and does the initial sorting of the packages and if there is one chance in three (rotating shifts) of a specific individual receiving a package, then one individual might handle as many as 2600 TI/yr. It appears, therefore, that the possibility exists that a single individual could receive more than 500 millirem/year. This possibility has been confirmed for a few individuals by recent state surveillance studies reported to the NRC. Subsequent handlings by transport workers are likely to be spread over several crews; thus, exposures to these individuals would be lower than that to the individuals who do the initial receiving and sorting.

H. Shipment by Freight Forwarders

The previously mentioned state surveillance studies surveyed four freight forwarder locations where overpacking of radiopharmaceutical packages is carried out. The average population

exposure associated with these operations was found to be 4 person-rem/year per location. It is estimated that there are no more than 10 such locations throughout the country, resulting in a maximum population exposure of 40 person-rem/yr.

I. Summary of Environmental Impact for Normal Transport

In summarizing the environmental impact from normal transport, it will be assumed that radiological impact is predominant and it will be summarized in some detail. The remaining impacts are summarized in the text and are secondary in nature. This is especially true when placed in the context of impacts that are directly traceable to the shipment of radioactive materials. Because radioactive materials are carried most often on vehicles whose prime purpose is to carry passengers or other freight, these secondary impacts would occur regardless of the presence of the radioactive material package.

I.1 Summary of Radiological Impact from Normal Transport

The radiological impact in terms of annual population doses is given in Table IV-8 for various population and transport modes. Table IV-9 shows similar information but classified by isotope or material shipped rather than by transport mode. From the data contained in these two tables, the following observations can be made:

1. The principal contributor to the population dose is the shipment of isotopes for medical use. While each such shipment emits at relatively low intensity, the number of such shipments is very large.
2. The principal contributors to exposure to the general population are the highway transport modes, followed by air and rail modes.
3. On the basis of person-rem per TI carried, the highway transport modes produce the

TABLE IV-8

Summary of Group Population Exposure to Radiation in Person-Rem*
as a Result of Transport of Radioactive Materials
by Various Transport Modes Under Normal Conditions
-1975 Standard Shipments-

Mode	Passengers	Crew	Attendants	Handlers	Surrounding Population				Total
					While Moving				
					Off Link	On Link	Stops	Storage	
Passenger Air	866	1	54	205	—	—	64	246	1436
Cargo Air	—	1	—	97	—	—	60	233	392
Truck (Interstate)	—	60	—	76	1042	16	721	183	2098
Rail (Freight)	—	7	—	16	366	—	6	39	434
Car and Van (Delivery)	—	14	—	187	3866	135	580	448	5229
SUBTOTALS	866	84		581	5273		1431	1149	9589

*All values rounded to nearest whole number

TABLE IV-9

Summary of Group Population Exposure to Radiation in Person-Rem*
as a Result of Transport of Various Radioactive
Materials Under Normal Conditions
-1975 Standards Shipments-

					Surrounding Population				
					While Moving				
Shipment	Passengers	Crew	Attendants	Handlers	Off Link	On Link	Stops	Storage	Total
Mo-99 (small	333	42	21	239	2362	71	694	480	4240
I-131 (small)	338	12	21	185	1498	50	328	347	2779
RAPH (small)	148	5	9	81	657	22	144	152	1217
Ir-192 (source)	—	9	—	7	152	2	62	16	248
Spent Fuel	—	10	—	19	428	1	32	46	535
Mo-99 (raw material)	—	5	—	26	74	1	131	62	299
Tc-99m	48	—	3	17	51	2	21	27	170
RAPH (Raw material)	—	—	—	5	21	1	9	11	46
I-131 (raw material)	—	—	—	2	7	—	3	4	16
Ir-192 (raw material)	—	—	—	1	2	—	1	1	5
Plutonium	—	1	—	1	20	—	7	3	33

*All values rounded to nearest whole number

largest effect for the material carried. Values for each mode are shown below.

Truck	1.4×10^{-2}	person-rem/TI carried
Secondary Modes	1.3×10^{-2}	"
Rail	1.3×10^{-2}	"
Passenger Air	6.8×10^{-3}	"
All Cargo Air	2.0×10^{-3}	"

When the mean person-rem/TI for secondary transport modes is added to that for each major mode, the ranking is as follows:

Truck	2.8×10^{-2}	person-rem/TI
Passenger Air	2.1×10^{-2}	"
All Cargo Air	1.6×10^{-2}	"
Rail	1.3×10^{-2}	"

4. The principal indicator of population exposure is the TI rating of the packages shipped by any mode. Since TI per package is largely a function of the shielding provided, reduction of TI per package and total TI shipped will have a mitigating effect on normal mode exposures.
5. The estimated total population dose in 1975 is 9589 person-rem. This dose was delivered over a one-year period and has the same general characteristics of other chronic exposures to radiation, such as natural background. The total population at risk is estimated to be about 20×10^6 people, based upon estimates of numbers of aircraft passengers, persons in air terminals, and persons living within one-half mile of truck and van routes. Thus, the average individual dose is approximately 0.5 mrem/year, which is a factor of 200 below the average individual exposure from background radiation.

6. The average individual dose results primarily from the transportation of radiopharmaceuticals and medical use isotopes. This dose is a factor of 20 smaller than the readily accepted dose resulting from the use of these materials, as shown in Table III-3.

7. For the year 1985, the volume of traffic in radioactive materials was projected for radiopharmaceuticals, spent fuel, plutonium, and irradiator sources (see Chapter I). While the projected growth rates in each sector differ, all are close to 10 percent per year, yielding volumes 2.6 times greater than for 1975. Projections of growth in population dose were made using the 1985 shipping estimates and the results are shown in Tables IV-10 and IV-11. Because no changes were made in mode split and other parameters in the computational model changed only slightly, population doses increase as expected by a factor of 2.5 in virtually every instance. The realism in these projections must be examined very closely, since small changes in mode split have an appreciable effect on the population dose.

TABLE IV-10

Summary of Group Population Exposure to Radiation in Person-Rem
as a Result of Transport of Radioactive Materials
by Various Transport Modes Under Normal Conditions
-1985 Standard Shipments-

					Surrounding Population				
					While Moving				
Mode	Passengers	Crew	Attendants	Handlers	Off Link	On Link	Stops	Storage	Total
Passenger Air	2249	4	40	532	—	—	166	639	3730
Cargo Air	—	4	—	252	—	—	157	605	1018
Truck (Interstate)	—	183	—	217	3148	42	2045	520	6155
Rail (Freight)	—	62	—	154	3463	1	58	371	4109
Car and Van (Delivery)	—	37	—	485	10040	348	1506	1163	13580
TOTAL	2249	290	140	1640	16650	391	3932	3298	28590

TABLE IV-11
Summary of Group Population Exposure to Radiation
in Person-Rem as a Result of Transport of Various
Radioactive Materials Under Normal Conditions
-1985 Standard Shipments-

Isotope Shipment	Passengers	Crew	Attendants	Handlers	Surrounding Population				
					While Moving				
					Off Link	On Link	Stops	Storage	Total
Mo-99 (small)	864	108	54	621	6137	180	1803	1246	11013
I-131 (small)	877	32	55	480	3892	129	852	902	7219
RAPH (small)	384	14	24	210	1707	57	373	395	3164
Ir-192 (source)	—	23	—	17	394	5	162	41	642
Spent Fuel	—	96	—	180	4050	9	299	432	5066
Mo-99 (raw material)	—	12	—	67	194	3	339	162	777
Tc-99m	124	1	8	44	133	5	55	71	441
Plutonium	—	4	—	3	66	1	15	6	95
RAPH (raw material)	—	—	—	12	54	2	22	29	119
I-131 (raw material)	—	—	—	4	19	1	8	10	42
Ir-192 (raw material)	—	—	—	1	6	—	3	3	13

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CHAPTER V

EFFECT OF TRANSPORT UNDER ACCIDENT CONDITIONS

A. Risk Assessment

In this chapter the accident-related risks of transporting radioactive materials are assessed. This risk analysis depends on the probability of the release of specific radioisotopes and the possible effects of these releases. The risk to the general public from the entire spectrum of accidents involving the transportation of radioactive materials is evaluated using the standard shipments model. The risk, expressed in terms of both person-rem/year and expected latent cancer fatalities is calculated for each standard shipment.

A flow chart for the general study method is shown in Figure V-1.

The risk to the general population may be expressed as follows:

$$\text{Risk}\left(\frac{\text{consequences}}{\text{unit time}}\right) = \text{Frequency}\left(\frac{\text{events}}{\text{unit time}}\right) \times \text{Magnitude}\left(\frac{\text{consequences}}{\text{event}}\right)$$

For computation of the accident-related risks, the frequency term corresponds to the probability of a radioactive material release in a transportation accident, and the magnitude term corresponds to the dose in person-rem delivered to the

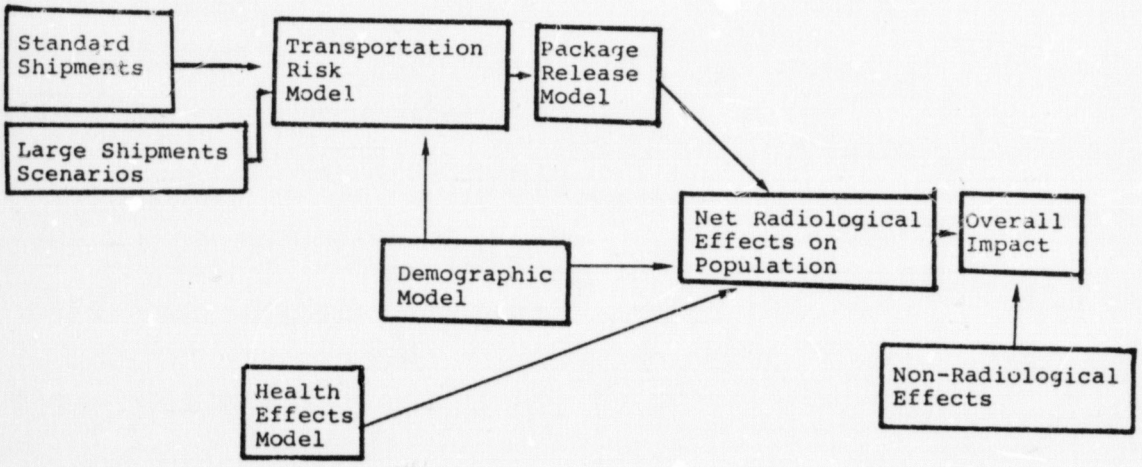


Figure V-1. Flow Chart for Accident Risk Analysis for Transportation of Radioactive Materials.

population as a consequence of the release. The probability of release includes the probability of packaging failure as well as transport accident probabilities. The direct radiological impact on any given individual is his exposure in rem. For the general population, the direct radiological risk is expressed in person-rem[1] (the dose integrated over the total exposed population) per year.

The most severe accidents are generally the least likely to occur. However, they usually arouse more critical attention than accidents having smaller consequences but occurring more frequently, even though both may involve the

same risk to the general population. Nevertheless, because of the interest in "worst case" accidents, selected scenarios involving large-quantity radioisotope shipments are also analyzed.

In order to assess risk, it is necessary to quantify radioactivity release by defining accident sequences. These sequences are delineated in a logic model which specifies the various events or combinations of events which can produce an environmental impact. The complete logic model is discussed in Appendix A.

Certain sequences resulting in environmental impacts can be readily identified as more likely than others, and these are emphasized in the risk assessment. Figure V-2 serve to illustrate the sequences of events leading to a potential impact resulting from a transportation accident in route. The direct radiological impacts to man are identified as the most important to consider among the possible contributors to the risk analysis. Indirect effects such as food-chain build-up are small, because accidents involving releases of radioactive materials occur infrequently. Figure V-3 shows that this direct impact to man may result from transportation by all modes. Each major transport mode, such as aircraft, includes sub-classes such as cargo-air, passenger-air, helicopter, etc., as illustrated in Figure V-4. Figure V-5 shows the contributors to the accident impact from transportation of radioactive materials by cargo aircraft. This impact includes the accident rate per vehicle-mile for accidents of a given severity, the fraction of accidents occurring in various population zones, and the dose due to a given release. The shipping scenario itself provides information concerning the number of shipments per year, the amount of material per shipment, and the distance traveled by a given shipment.

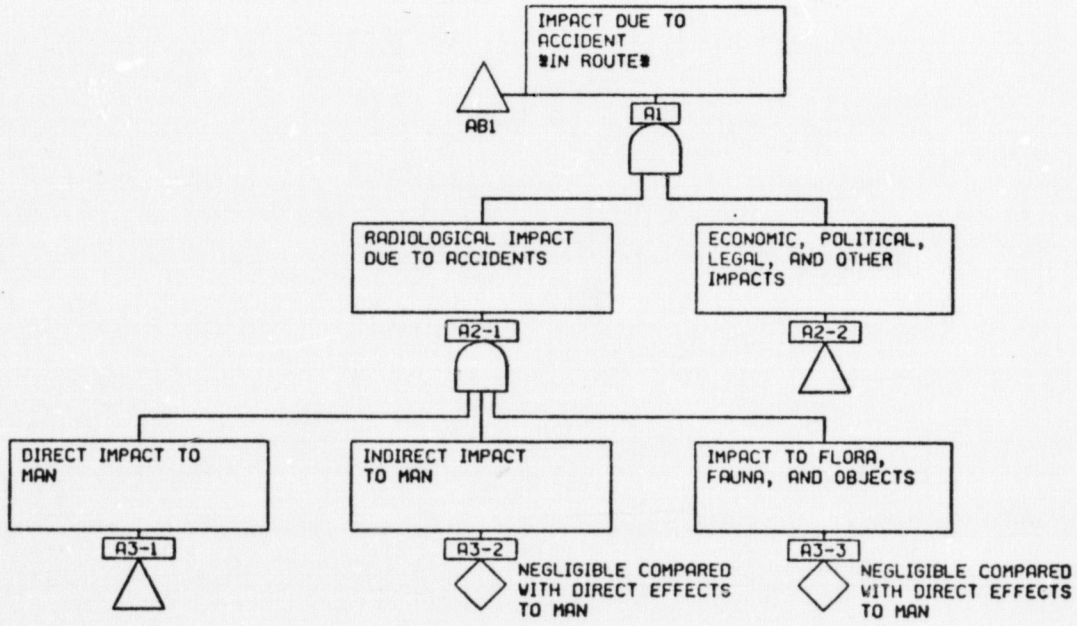


FIGURE V-2. Logic Model of Contributors to Impacts due to Accidents while in Route

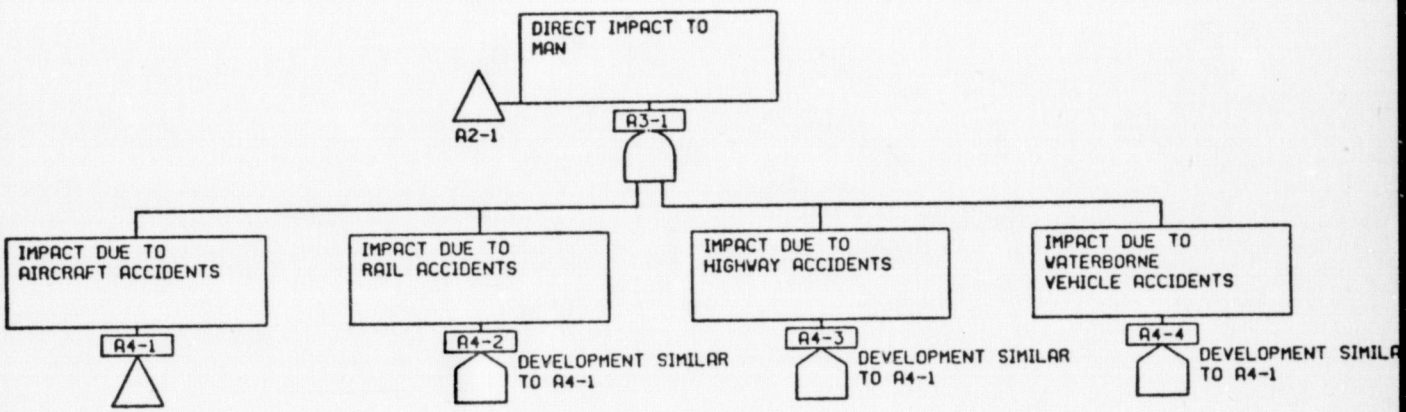


FIGURE V-3. Logic Model of Transportation Mode Contributors to Direct Impact to Man from Transporation Accidents

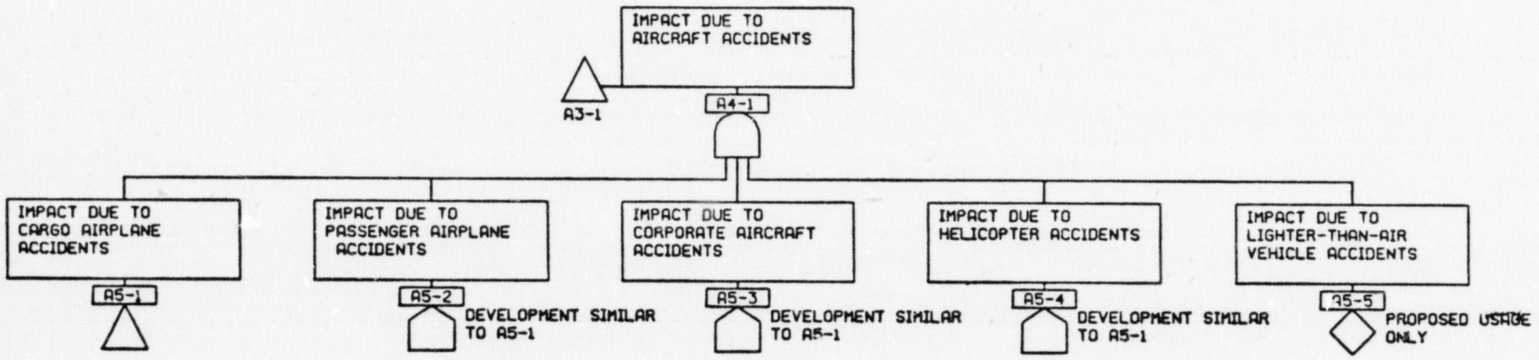


FIGURE V-4. Logic Model for Analysis of Impacts Resulting from Aircraft Accidents

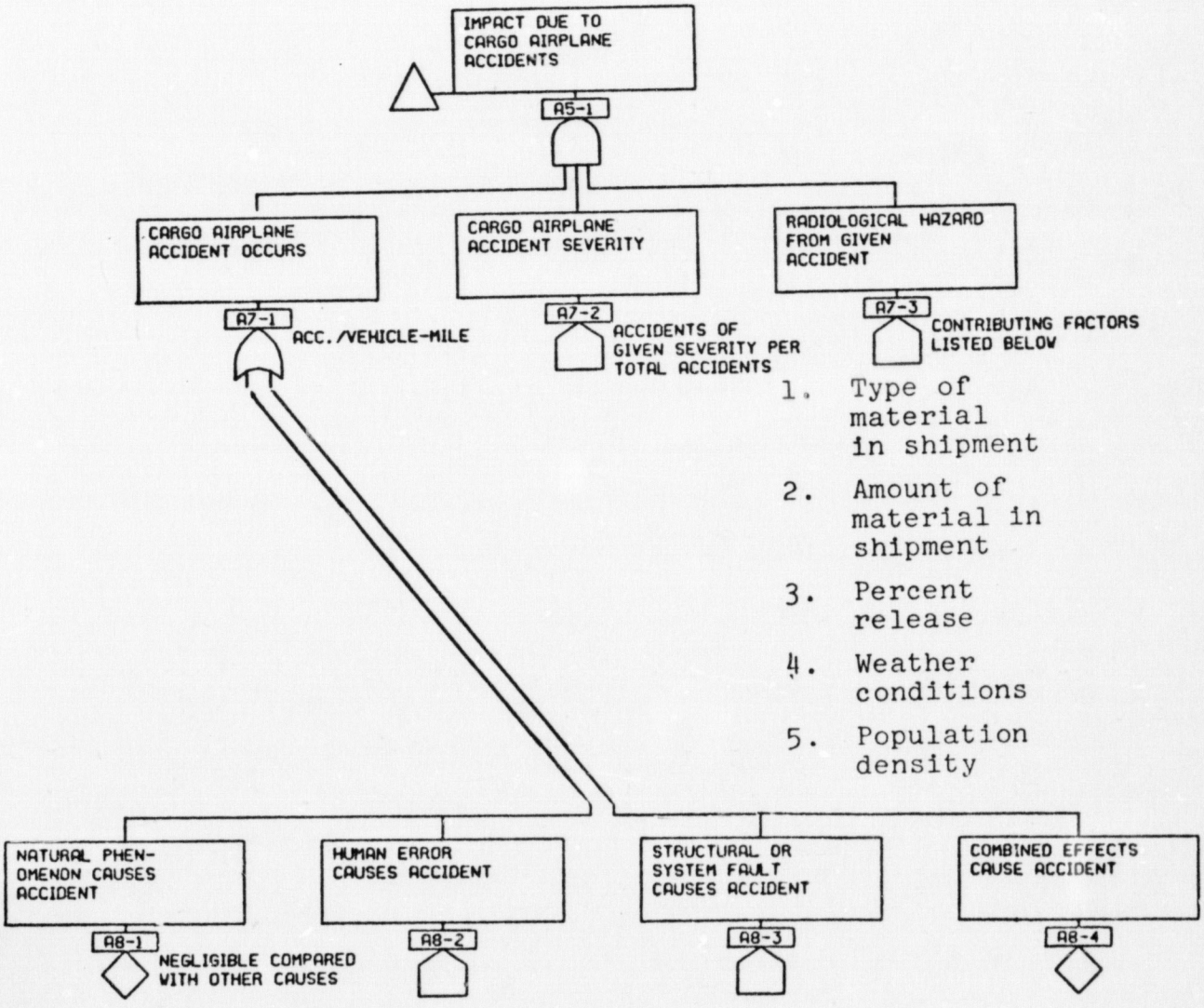


FIGURE V-5. Logic Model for Analysis of Cargo Aircraft Accidents

The general expression for the risk in terms of annual person-rem for a j^{th} type of shipment can be formulated as follows:

$$R_j = N_j A_j B_j \sum_{i=1}^{n} C_i D_{ij} K_{ij} \qquad (1)$$

where N_j = number of packages in the shipment

A_j = number of curies (grams) per package

B_j = number of vehicle miles per year for this type shipment

C_i = probability per vehicle mile of an accident of severity class i

D_{ij} = estimated release fraction for the type shipment being considered and for the accident of severity class i

K_{ij} = number of person-rem per curie (gram) released

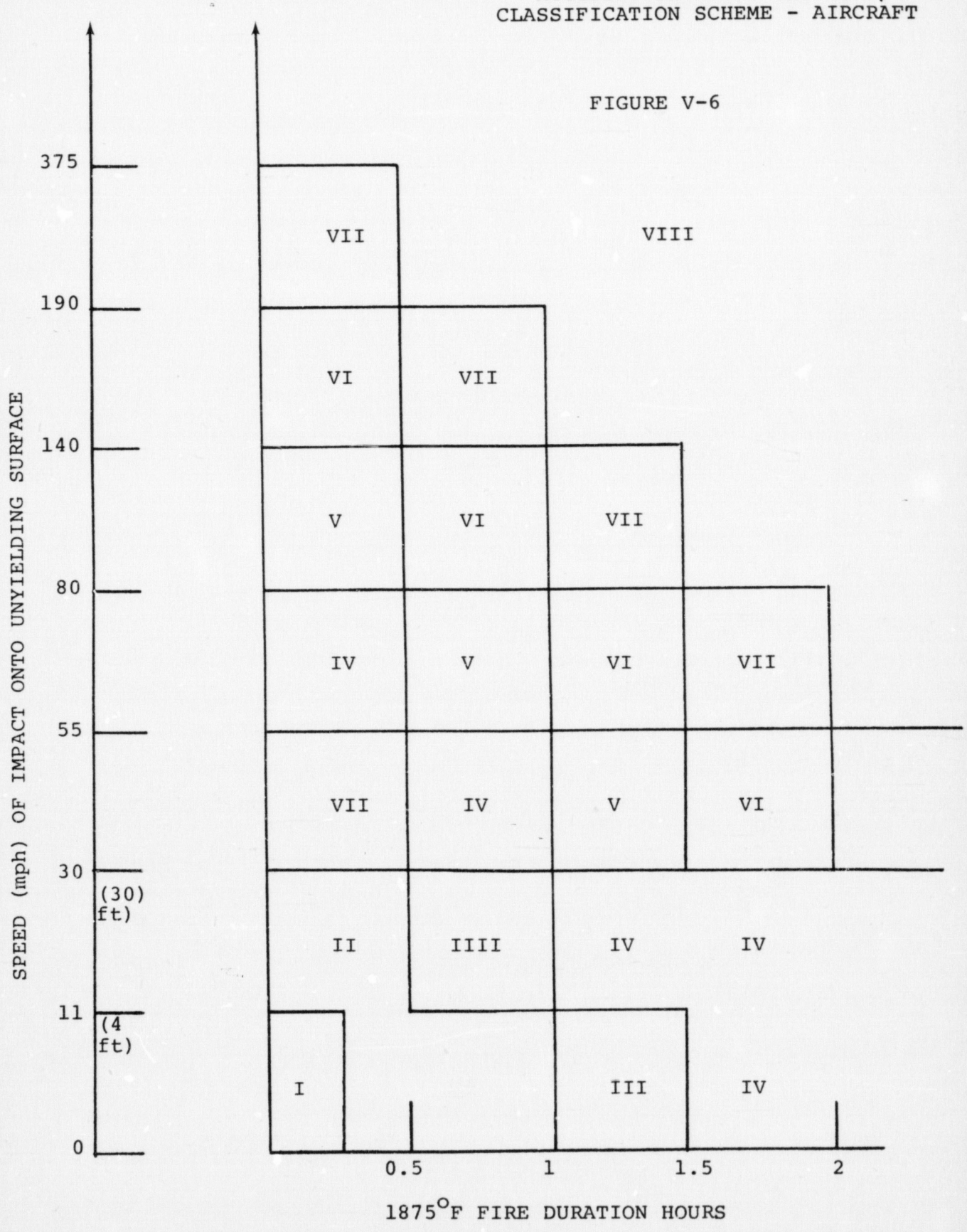
n = number of accident severity classes considered.

B. Accident Statistics and Release Fractions

Equation (1) shows that release of radioactive materials is dependent on the accident probability C_i and the release fraction D_{ij}. These terms are both a function of the accident severity. Brobst[2] has classified accidents for rail, truck and barge into five severity categories and tabulated the probabilities per vehicle mile of an accident of a given severity for each category and ea ı mode. Accident probabilities have also been compiled by Clarke, et al,[3] for aircraft,[4] motor carrier,[5] and rail[6] modes of transportation. While Brobst considered only impact and fire, Clarke, et al, include the effects of crush and puncture. The

ACCIDENT SEVERITY CATEGORY,
CLASSIFICATION SCHEME - AIRCRAFT

FIGURE V-6



differences in approach to the severity classification problem prompted an attempt to provide a means of comparing accidents of one transport mode with those of another, including aircraft accidents.

In this section, the accident severity classification scheme used for this impact assessment is discussed and accident probabilities and release fractions are assigned to the accident severity categories for air, truck, and rail transport modes.

B.1 Aircraft Accidents

The classification scheme devised for aircraft accidents is illustrated in Figure V-6. The ordinate is the speed of impact onto an unyielding surface, and the abscissa is the duration of an 1875°F fire. The results of Clarke et al[4] indicate that impact speed and fire duration are the appropriate parameters with which to categorize aircraft accidents. Unyielding surface rather than real surface impacts were chosen in order to make use of the data of Clarke et al.[4] and to facilitate comparison with the regulatory standards.

The first two impact scale divisions were chosen to correspond to standards for Type A and Type B packagings, respectively. Thus Category I impacts, equivalent to a drop from 4 feet or less onto an unyielding surface, should not produce a loss of containment or shielding in a Type A package. A 30 feet equivalent drop was chosen as the division between a Type II and Type III impact accident, corresponding to the Type B container test specification. The remaining impact category divisions were chosen more or less arbitrarily from

the aircraft accident data compiled by Clarke et al.[4] in such a way that

95% of the impact accidents are severity Type VII or less,
85% of the impact accidents are severity Type VI or less,
80% of the impact accidents are severity Type V or less,
70% of the impact accidents are severity Type IV or less, and
60% of the impact accidents are severity Type III or less.

The fire duration category divisions are chosen in such a way that, with the exception of certain category IV accidents, increasing the fire duration by 30 minutes is equivalent to increasing the impact to the next higher level. Impacts at less than 30 mph would not be sufficient to produce an accident of severity category V or greater regardless of how long the fire burned. The fire temperature was chosen as 1875^{o}F to facilitate comparison with previous data[3] and to correspond roughly to the temperature of a jet fuel fire.

Note that category I accidents can involve a fire of as much as fifteen minutes duration. A Type A package involved in a category I accident in which a fire occurs would not be required by the regulations to survive the accident without loss of shielding or containment.

The fractions f_i of aircraft accidents expected in each of the eight aircraft accident severity categories are given in Table V-1. The numbers under the column heading "Unyielding Surface" are taken from the accident severity data of Clark et al.[4] adapted to the accident severity classification scheme used in this study.

TABLE V-1. Fractional Occurrences for Aircraft Accidents by Accident Severity Category and Population Density Zone.

ACCIDENT SEVERITY CATEGORY	FRACTIONAL OCCURRENCES f_i		FRACTIONAL OCCURRENCES ACCORDING TO POPULATION DENSITY ZONES		
	Unyielding Surface	Real Surfaces	Low	Medium	High
I	.57	.57	.05	.9	.05
II	.16	.16	.05	.9	.05
III	.09	.099	.1	.8	.1
IV	.05	.077	.1	.8	.1
V	.03	.033	.3	.6	.1
VI	.03	.036	.3	.6	.1
VII	.04	.022	.98	.01	.01
VIII	.03	.003	.98	.01	.01
TOTAL	1.00	1.00			

OVERALL ACCIDENT RATE[4] = 1.8×10^{-8} accidents/mile for passenger aircraft
5.6×10^{-8} accidents/mile for cargo aircraft

The fractional occurrences listed under the heading "Real Surfaces" are the results of an attempt to take into account the fact that most aircraft accidents involve impact onto surfaces which provide at least some cushioning effect and result in impact forces which are less severe than would occur on an unyielding surface. These fractional occurrences are obtained by de-rating those for unyielding surfaces in the following way. It was estimated that only 10 percent of the land area of the United States could be considered as "unyielding surfaces," e.g. rock, concrete, or rock covered by shallow soil layers. Thirty percent of the land area is forested, and the remaining 60 percent consists of soil, farmland, grassland, etc. The greatest mitigation in severity would be expected for impacts onto water, but since only about 2 percent of the surface area of the United States is water, this is neglected. Impacts into forested areas are expected to be considerably less severe than unyielding surface impacts. Since roughly 30 percent of the land area is forested, 30 percent of the accidents in each category are de-rated by two severity levels to take this into account. The remaining 60 percent of the accidents in each category are de-rated one severity level.

The de-rating of accident severities was made beginning with category VIII and working back as far as category IV. No real surface effects were expected for categories I and II, since these low-severity accidents usually occur while the aircraft is on the ground at the airport.

A sub-classification within each category was made to estimate the fraction of those accidents which occur in a given population density zone. Three zones were used in this assessment: low, medium, and high, and characterized by

average population densities of 40, 400, and 4000 persons/km^2, respectively. Accidents of severities I and II occur at airports. Since most airports are in suburban, or medium, population density zones, 90 percent of all class I and II accidents are estimated to occur in medium density zones, with 5 percent each in low and high density zones.

Accident categories III-VI are expected to be mainly takeoff and landing accidents and thus occur near airports. The fractional occurrence in low population density zones increases somewhat with accident severity, since a greater percentage of category V and VI accidents occur at some distance from the airport where aircraft speeds are usually greater.

Accidents of severity VII or VIII are mainly in-flight accidents and are expected to occur randomly. They are very strongly weighted toward the rural, or low density, areas, since about 98 percent of the land area of the United States is considered rural.[7] The remainder is estimated to be split between medium and high population density zones.

The accident rates for passenger and cargo aircraft, independent of severity level, are 1.8×10^{-8} and 5.6×10^{-8} accidents per mile, respectively.[4] The accident rate C_i for severity level i is obtained by multiplying the overall accident rate by the fractional occurrence f_i for real surfaces for that severity class. For each scenario in the standard shipment model three risks are computed, assuming the shipments occur entirely in either a low, medium, or high population density zone. The actual risk is obtained by forming the sum of these three risk values weighted by the fractional

accident occurrence in each population density zone for that scenario. This same computational technique is used for all transport modes.

5.2 Truck Accidents

The severity classification scheme for truck accidents is shown in Figure V-7. In this case the ordinate is crush force rather than impact. Clarke et al.[5] have shown that in the case of accidents involving motor carriers the dominant factors in the determination of accident severity are crush and fire. Thus, although the impact speeds in truck accidents are usually much less than in aircraft accidents, the crush forces can be severe, and significant package damage can result.

The fractional occurrences f_i of truck accidents in each of the eight severity categories are shown in Table V-2. No real-surface de-ratings are involved in this case, since the dominant effect is crush rather than impact. The fractional occurrences were taken from the data of Clarke et al.[5] Note that the f_i-values for categories VII and VIII are much lower than for aircraft accidents. The overall accident rate for motor carriers transporting hazardous materials is 1.7×10^{-6} accidents/mile.[2]

The estimated fractions of truck accidents in each severity category occurring in each population density zone are also shown in Table V-2. The very low severity accidents are expected to occur mainly in urban areas. The table reflects a gradual shift of accidents to rural areas with increasing severity.

ACCIDENT SEVERITY CATEGORY
CLASSIFICATION SCHEME - MOTOR TRUCKS

FIGURE V-7.

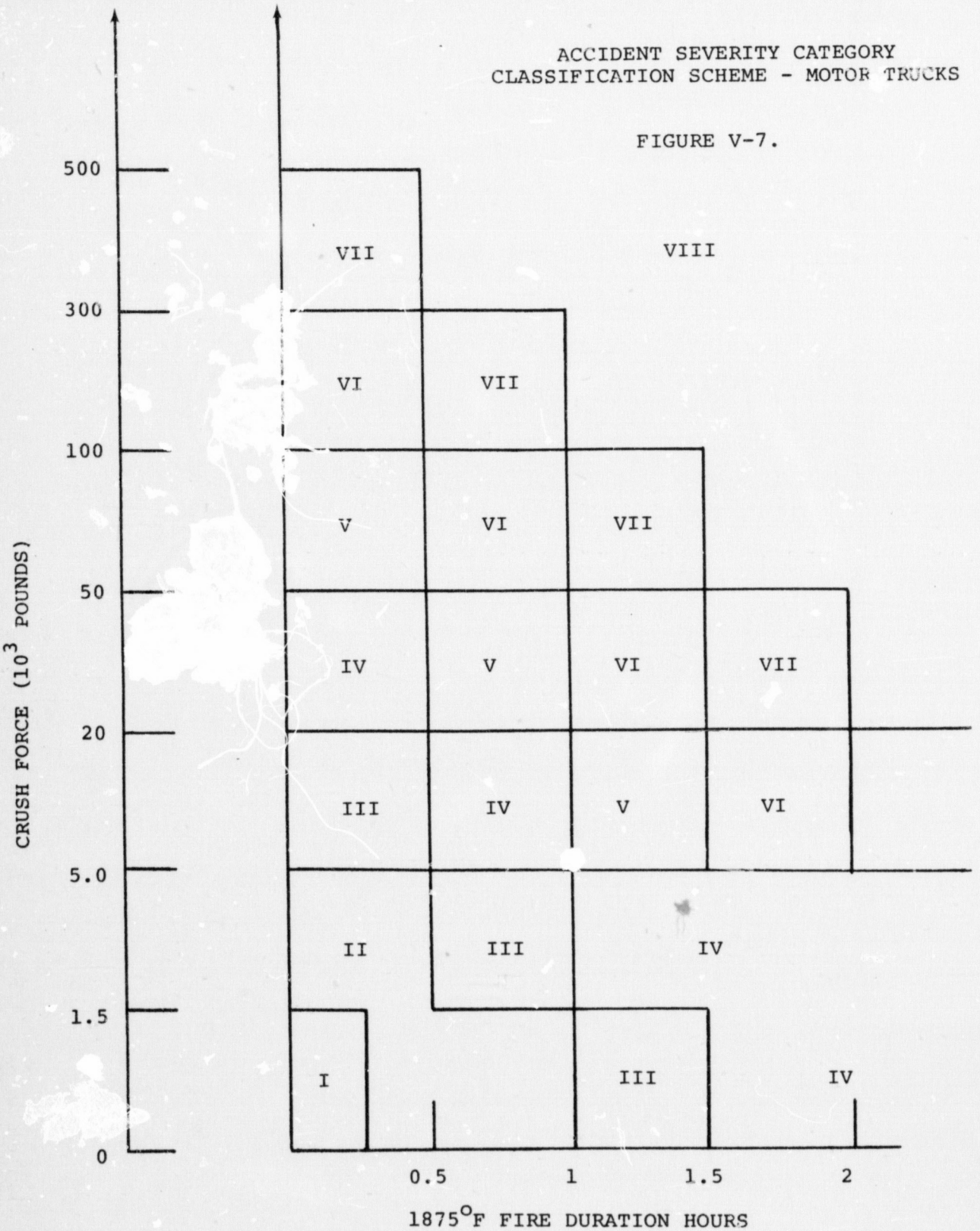


TABLE V-2. Fractional Occurrences for Truck Accidents by Accident Severity Category and Population Density Zone.

ACCIDENT SEVERITY CATEGORY	FRACTIONAL OCCURRENCES f_i	FRACTIONAL OCCURRENCES ACCORDING TO POPULATION DENSITY ZONES		
		Low	Medium	High
I	.55	.1	.1	.8
II	.36	.1	.1	.8
III	.07	.3	.4	.3
IV	.016	.3	.4	.3
V	.0028	.5	.3	.2
VI	.0011	.7	.2	.1
VII	9.5×10^{-5}	.8	.1	.1
VIII	1.5×10^{-5}	.9	.05	.05

OVERALL ACCIDENT RATE[2] = 1.7 x 10-6 accidents/mile

B.3 Delivery Van Accidents

The accident severity classification scheme for delivery vans is the same as that for trucks as shown in Figure V-7. The fractional occurrences are shown in Table V-3. and are taken to be the same as for trucks. The overall accident rate, 1.7 x 10-6 accidents/mile, is also taken to be the same as for trucks. The fractional occurrences in the three population zones, however, are different. In the standard shipments model delivery vans are used only as a secondary transport mode. There is practically no rural travel; most of the radioactive materials transport in delivery vans is to and from airports, truck terminals, and railroad depots. There are expected to be more low severity accidents in high population density zones and more very severe accidents on freeways in medium population density zones.

B.4 Train Accidents

Figure V-8 illustrates the accident severity classification scheme used for train accidents. The ordinate in this case is impact velocity, taking into account the effects of puncture. In their analysis of train accidents Clarke et al.[6] considered crush to be an important factor. However, they were concerned with containers shipped in carload lots with the crush forces resulting from interaction with other cargo in the rail car. The only rail transport considered in the standard shipments model (see Table I-2) involved spent fuel casks, and only one cask is usually transported on a single rail car. In any case, the substitution of crush forces for puncture on the ordinate and the resulting changes in accident probabilities have very little effect upon the results of the risk calculation.

TABLE V-3. Fractional Occurrences for Delivery Van Accidents by Accident Severity Category and Population Density Zone.

ACCIDENT SEVERITY CATEGORY	FRACTIONAL OCCURRENCES f_i	FRACTIONAL OCCURRENCES ACCORDING TO POPULATION DENSITY ZONES		
		Low	Medium	High
I	.55	.01	.39	.60
II	.36	.01	.39	.60
III	.07	.01	.39	.60
IV	.016	.01	.50	.49
V	.0028	.01	.50	.48
VI	.0011	.01	.50	.49
VII	8.5×10^{-5}	.01	.60	.39
VIII	1.5×10^{-5}	.01	.60	.39

OVERALL ACCIDENT RATE = 1.7×10^{-6} accidents/mile

ACCIDENT SEVERITY CATEGORY
CLASSIFICATION SCHEME - TRAIN

FIGURE V-8.

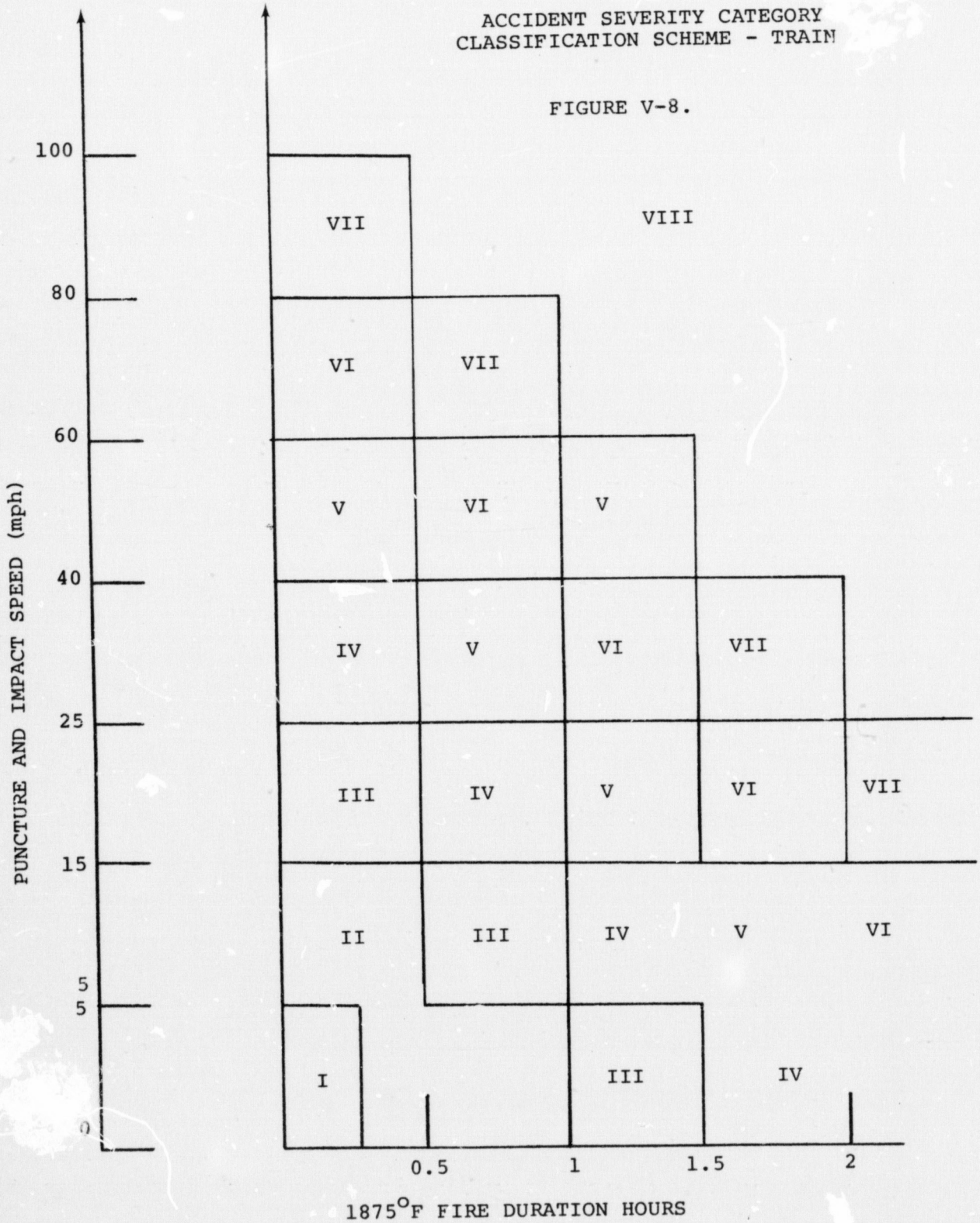


Table V-4 lists the fractional occurrences for train accidents by severity class and by population density zone. The f_i-values were taken from the data of Clarke et al.[6] As with truck accidents, no real-surface effect de-rating of the fractional occurrences is required, since the predominant effect in the most severe accidents is puncture. The overall accidents rate is 1.5×10^{-6} rail-car accidents/rail-car mile, assuming an average train length of 70 cars and average of ten cars involved in each accident.[6] Only 10 percent of the accidents are estimated to occur in high population density zones, regardless of severity. The remainder of train accidents are estimated to be equally distributed between low and medium population density zones.

B.5 Helicopter Accidents

Helicopter accidents are classified in the same way as aircraft accidents (Figure V-6). The overall accident rate is 1.0×10^{-6} accidents/mile[8] and the fractional occurrence f_i, shown in Table V-5, are taken to be the same as for aircraft impacting on real surfaces. However, the fractional occurrences in the three population density zones are different since helicopters are expected to be used as a secondary transport mode to and from the airport. None of the standard shipments involve helicopter transport, but one of the alternatives considered in Chapter VI considers the risk involved in the transport of strategic special nuclear material by cargo aircraft, with helicopter as a secondary mode.

Accidents represented by the first two severity categories occur while the helicopter is on the ground either at the airport or at a pick-up or delivery point, all of which would be

TABLE V-4. Fractional Occurrences for Train Accidents by Accident Severity Category and Population Density Zone

ACCIDENT SEVERITY CATEGORY	FRACTIONAL OCCURRENCES f_i	FRACTIONAL OCCURRENCES ACCORDING TO POPULATION DENSITY ZONES		
		Low	Medium	High
I	.50	.45	.45	.10
II	.30	.45	.45	.10
III	.18	.45	.45	.10
IV	.018	.45	.45	.10
V	.0018	.45	.45	.10
VI	1.3×10^{-4}	.45	.45	.10
VII	6.0×10^{-5}	.45	.45	.10
VIII	1.0×10^{-5}	.45	.45	.10

OVERALL ACCIDENT RATE = 1.5×10^{-6} rail-car accidents/rail-car mile

TABLE V-5. Fractional Occurrences for Helicopter Accidents by Accident Severity Category and Population Density Zone.

ACCIDENT SEVERITY CATEGORY	FRACTIONAL OCCURRENCES f_i (REAL SURFACES)†	FRACTIONAL OCCURRENCES ACCORDING TO POPULATION DENSITY ZONES		
		Low	Medium	High
I	.57	.35	.60	.05
II	.16	.35	.60	.05
III	.099	.45	.45	.10
IV	.077	.45	.45	.10
V	.033	.45	.45	.10
VI	.036	.45	.45	.10
VII	.022	.19	.80	.01
VIII	.003	.19	.80	.01

OVERALL ACCIDENT RATE = 5.6×10^{-8} accidents/mile

located primarily in medium and low population density zones. It is anticipated that helicopter flights, particularly those carrying plutonium would be routed to avoid flying over high population density zones whenever possible. Thus, the take-off and landing accidents (severity categories III-VI) as well as the in-flight type accidents (categories VII-VIII) are expected to be concentrated in the medium and low population density zones. Category VII and VIII type accidents involving helicopters are considered to be mid-air collisions, and would be expected to occur mainly in the immediate vicinity of an airport; thus most of these accidents should occur in medium population density zones.

B.6 Release Fractions

In order to assess the risk of a transportation accident involving radioactive material it is also necessary to know how any given package will behave when involved in an accident of a given severity. The fraction of the total package contents which escapes a damaged package is called the release fraction. Until recently, there was little information available regarding the behavior of typical radioactive material containers under extreme accident conditions, since the packaging standards do not require testing to failure. According to recent tests conducted at Sandia Laboratories, present shipping containers are considerably better than the standards require.[9]

Two release fraction models are postulated for the risk analysis and are given in Table V-2. Model I would be an accurate model if packagings were no better than required by the present standards. Model I assumes complete loss of contents for Type A containers encountering accident severities

TABLE V-6.

Package Release Fraction* Estimates for Each of the Release Models used Versus Accident Severity Level

ACCIDENT SEVERITY CATEGORY	MODEL I		MODEL II	
	Type A	Type B	Type A	Type B
I	0	0	0	0
II	1	0	0	0
III	1	1	0	0
IV	1	1	0	0
V	1	1	.1	0
VI	1	1	.2	0
VII	1	1	.5	.1
VIII	1	1	1	.5

*For special form materials, fractional release refers to fractional exposure of the source.

greater than category I and complete loss of contents for Type B containers involved in accidents of severity greater than category II. The second model, Model II, is based upon a limited amount of data for containers currently being tested at Sandia Labs.[7] In the tests a certain Type B container lost as much as 6% of its contents when subjected to category VII impact conditions. However, when the tests were repeated with impact onto soil rather than onto an "unyielding" surface, as in the first test series, no loss of contents occurred. A typical Type A Mo-99 generator package was also tested at category IV impact conditions (onto an unyielding surface). No loss of contents resulted; but package damage was extensive and release seemed likely for a slightly more severe test. Thus, typical containers are probably better than Model II would indicate. However, since there have been only a limited number of containers tested, Model II was used in the risk assessment as a conservative approximation to the behavior of real containers in an accident environment.

Spent fuel casks are treated in the same way as Type B containers, except that release fractions apply only to the gaseous and volatile components of the spent fuel. In that case the maximum release from a spent fuel cask is scaled by the Type B release fractions for the eight accident severity categories and for each of the package release models. It is further considered that the remaining fission products are retained within the fuel elements or shipping casks and present only an external radiation hazard. A previous analysis[10] has determined that the external radiation hazard from a spent fuel cask involved in a severe accident is negligible compared to the hazard due to the released material.

C. General Consequences of Release

Once release has occurred on land, in the atmosphere or in water, dispersion of the radioactive materials can proceed to produce environmental impacts such as external radiation dose, external foodstuff contamination, or buildup in the food chain. Certain of the most hazardous radionuclides transported were discussed in Chapter III in terms of their radiation characteristics. It was found that certain of the long half-life gamma emitters such as Co^{60} and the alpha emitters like plutonium posed the greatest hazards in terms of potential consequence if released.

Consequences of largest magnitude result from release to the atmosphere following an accident. Atmospheric transport and diffusion can disperse the radionuclide over large areas. The degree of dispersion is determined by atmospheric turbulence which is a function of time of day, cloudiness, surface characteristics and other parameters. The deposition of radionuclides associated with the passage of a cloud of released material can have a very complex environmental impact. Some possible routes for generating a consequence in man are summarized in Figure V-9. The impacts due to gamma emitters are largely involved with direct dose to man as external or internal radiation sources; but material which emits alpha radiation can produce large radiological consequences when aerosolized and breathed by man. Figure V-9 shows that deposited radionuclides can also become part of the food chain. They can be transferred from soil, to vegetation, to animals, and eventually to man. Comtamination in plants is characterized by multiple pathways including direct deposition of particulate and indirect take-up by leaching from soil. From the standpoint of man, I^{131} and Cs^{137} can produce impacts via the

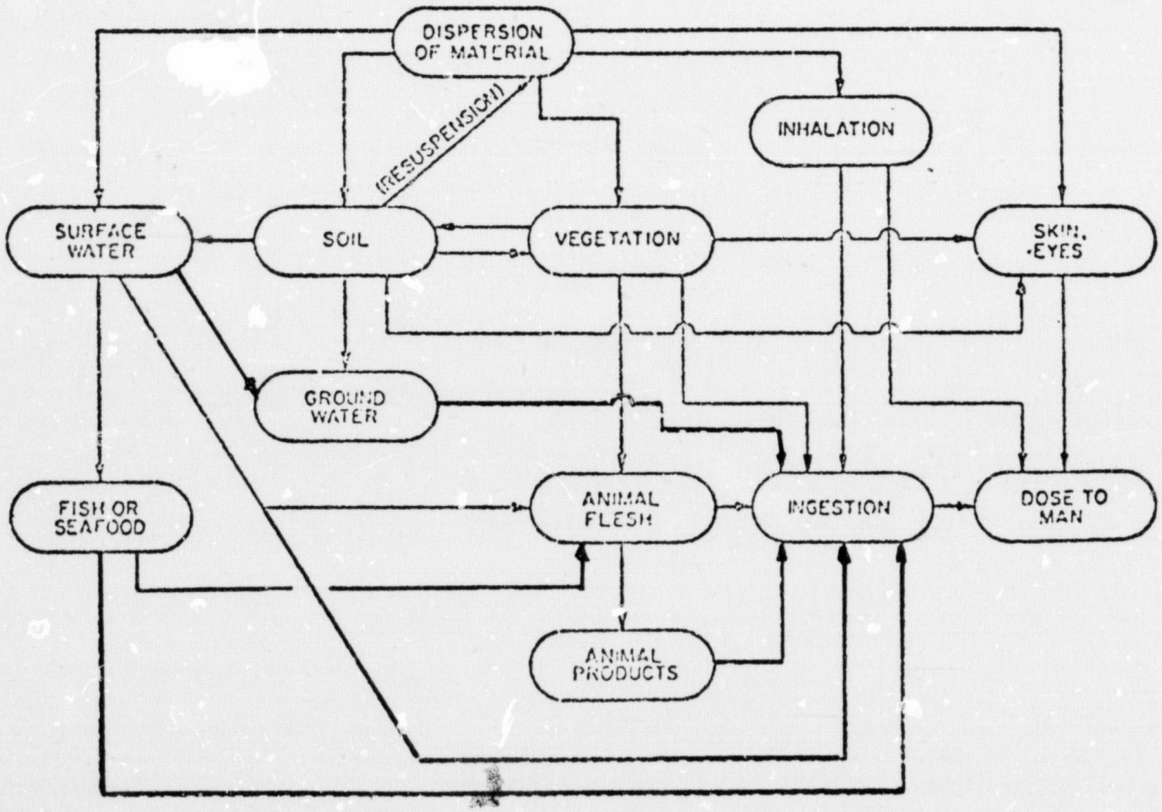


Figure V-9. Possible Routes to Man from Radionuclide Release

grass-cow-milk-meat cycle. The principal hazard from I^{131} results more from intake of milk than meat as a result of its relatively short half-life.

Figure V-9 shows that the aquatic environment can be affected directly from release or indirectly from transfer from the terrestrial sphere. Consequences to the aquatic environment are less well understood than for the land, due partly to the complex interaction of the large number of plant and animal species which inhabit these regions.

The consequences model is based on the Gaussian diffusion model widely used in analysis of atmospheric transport and diffusion. The calculation is initiated with a cloud of aerosolized debris at the accident site. The distribution of aerosolized material with cloud height are specified according to results obtained from Project Roller Coaster[11] which involved detonation of weapon simulants characteristic of that era. The use of such an initial distribution is justified for accidents in which fires or residual energy provides an aerosol cloud to be released from the accident site. The cloud is assumed to have an initial height of 10 meters above ground for all cases considered in this report. As a result, doses calculated using this model are conservative, particularly when an accident involves a large energy release which can carry aerosolized materials to great heights.

Transport and diffusion of the aerosol cloud is described using climatological distributions of horizontal and vertical components of turbulence intensities and wind speed. A year or more of data record for these parameters is used in the

model which was obtained at two different locations. The model allows estimates to be made of the fraction of the time that a specified dose to an average adult man in rem is exceeded as a function of the downwind distance and the amount of aerosolized material involved.

An example of the output obtained here from the model is shown in Figure V-10. The ordinate is the area on the ground in $(\text{meters})^2$ throughout which exposed individuals receive a radiation dose exceeding 0.8 rem for each kilogram of Pu-239 dispersed in plumes of various heights. The size of the affected area depends on local meteorological conditions which, for a randomly occurring accident, have a specific occurrence distribution. As a result, the x-coordinate represents the fraction of time a randomly occurring accident produces an area smaller than that shown on the y-coordinate for the condition of the calculation.

In order to obtain consequences in terms of person-rem, population density values of 4000, 400, and 40 persons/km^2 are used to represent areas of high, medium and low population. Approximately 98%, 1.9%, and 0.1% of the United States area respectively, has population density lower than these values.

Shielding from buildings can act to reduce exposure to the population, especially in high density urban environments. Buildings afford protection to their occupants by reducing direct radiation exposure and also by lowering particle concentrations within the buildings. This reduced hazard results from deposition during seepage of air through the walls of the structures and by capture on ventilation system filters. These effects are difficult to accurately assess, but Cohen[12]

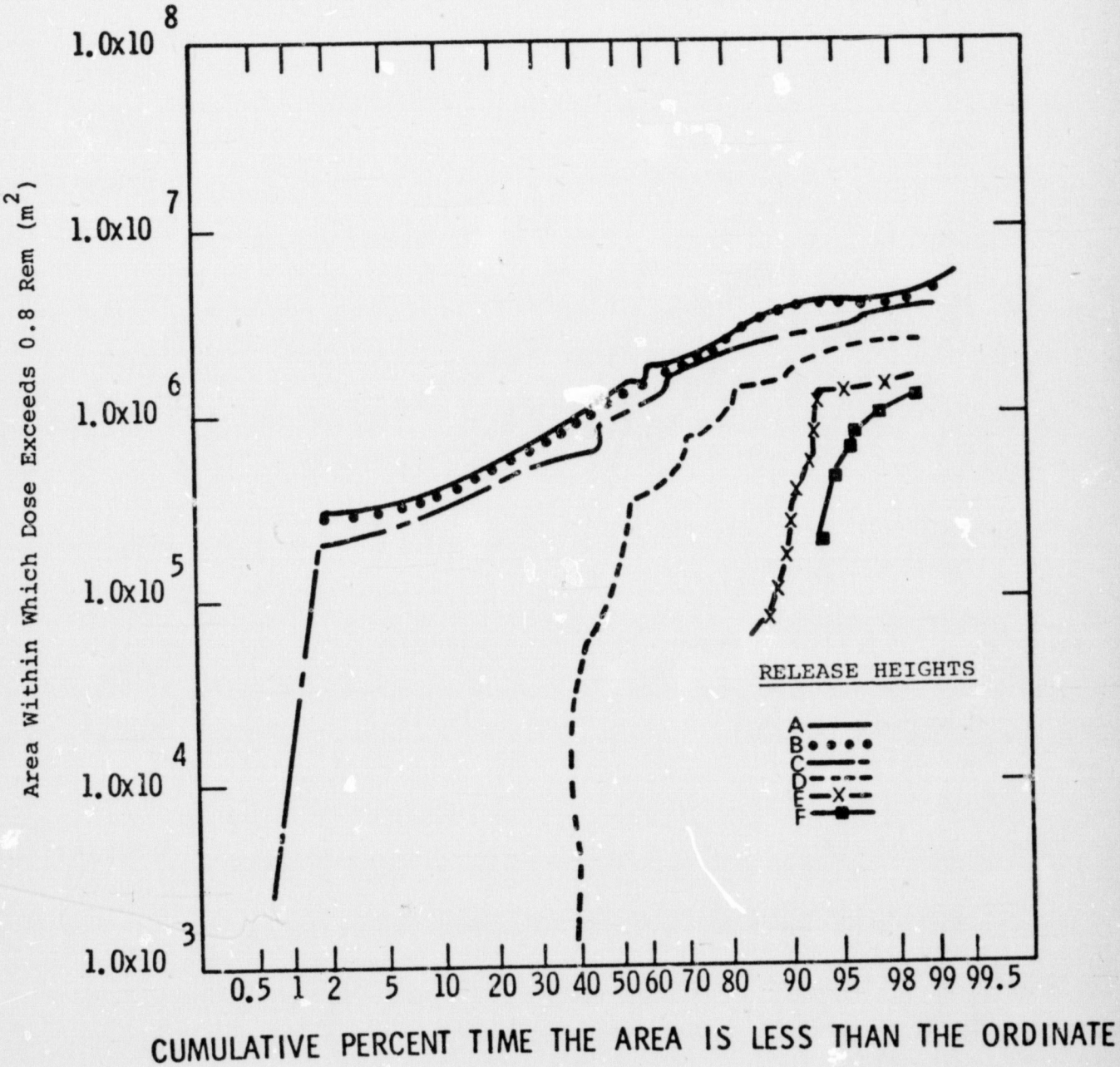


FIGURE V-10. Affected Area versus Probability Percent of the time a randomly occurring accident will produce an area enclosing dose exceeding .8 rem for dispersal of 1 kg of Pu-239 and cloud heights of: A = 10 meters, B = 25 meters, C = 60 meters, D = 160 meters, E = 400 meters and F = 1000 meters

has estimated that doses might be reduced by a factor of three. Because of the uncertainty in estimating the impact of this factor and the differences between the problem treated by Cohen and that considered here, no reduction in dose as a result of shielding has been included in these calculations.

D. Scenarios

In order to assess maximum consequences due to accident involving shipment of radioactive material, certain large shipment scenarios were analyzed. These are summarized in Table V-7. They include actual large Mo-99 and I-131 raw material shipments identified in the radiopharmaceutical industry, a large Co-60 irradiator source, and a large PuO_2 shipment identified in the nuclear fuel cycle.

In order to assess risk due to accidents involving shipment of radioactive material, a list of standard shipments was compiled which is representative of current shipping of radioactive materials. This standard shipping model is shown in Table V-8. Information concerning curies/package and other shipping data were ascertained from a previous survey,[13] from direct contacts with shippers, and from the ongoing Battelle study of radioactive material shipments. According to the previous survey, three materials: molybdenum-99, technetium-99m, and iodine (including the isotopes I-123, I-125 and I-131) accounted for over 75 percent of the radiopharmaceutical packages shipped. For the risk estimate, all other radiopharmaceuticals were lumped together into one group called "RAPH." Iridium-192 is used as a model for the transportation of radiographic materials; "RAPH" is assumed to act like Iodine-131.

TABLE V-7

Large Shipment Scenarios Used to Assess
Maximum Consequence Resulting from Accidents

Scenario	Material	Curies (kg)/Pkg	Pkg/Shipment
1	I-131 source	1,000.0	1
2	Mo-99 source material	3,000.0	1
3	Co-60 irradiator source (special form)	1,000,000.0	1
4	PuO_2	(5.0)	4

The special form Ir-192 material is encapsulated, therefore, in the calculations of consequences due to release, the material was assumed to present only a direct radiation hazard. The values used for shipments per year for each scenario are summarized in Table V-9. It can be noted from Tables V-8 and V-9 that a large number of shipments by aircraft and truck/van of certain medical use materials of low curie activity are known to occur on an annual basis. Radiographic material such as Ir^{192} are shipped principally by truck. Plutonium as well as molybdenum and iodine raw materials involve shipment by truck or cargo aircraft. Spent fuel is shipped principally by rail or truck in a specially designed cask.[14] The estimated mileages for each scenario by the various transportation modes are summarized in Table V-10.

E. Consequences Analysis

The population doses (in person-rem) for the transportation scenarios identified in Tables V-7 and V-8 were determined using the Gaussian plume dispersal model output shown in Figure V-10. Outputs were calculated for many different values of the source term and dose. The areas chosen to represent that affected by the aerosol cloud correspond to the 95% value on the abscissa. This area would not be exceeded in 95% of all accidents and is an area 2 to 5 times larger than the mean affected area for each combination of source and dose. These areas were cross plotted as a function of rem/gram of respirable plutonium to obtain Figure V-11. A cloud height of 10 meters was assumed as a conservative estimate of the release effects produced by an aircraft impact into the ground or by a severe truck accident.

The curve shown in Figure V-11 is valid for the dispersion of any aerosolized material, but has been expressed (as a

TABLE V-8

Standard Shipments Studied to Assess
Risk Resulting from Accidents

Standard Shipment	Material	Curies (kg)/Pkg	Pkg Type	Pkg/Shipment
1	Mo - Tc Generator	0.6	A	2
2	Tc^{99m}	0.28	A	3
3	I^{131}	0.012	A	3
4	Ir^{192}	100.0	B(special form)	1
5	Ir^{192} (Raw Material)	5000.0	B	1
6	PuO_2	(5.4)	B	1
7	Mo^{99} Source Material	80	B	1
8	I^{131} Source Material	56.7	B	1
9	Spent Fuel*			
	Kr^{85}	2000.0		
	Iodine Isotopes	2.0	B(cask)	1
	Fission Products	800.0		
10	Other radio-pharmaceuticals (RAPH-small)***	0.042	A	3
11	Other radio-pharmaceuticals (RAPH-large)***	74.0	B	1

*These values are the curies within the fuel elements available for release in an accident.

**Modeled as volatile cesium-137

***Modeled as iodine-131

TABLE V-9

Shipments per Year (1975) for the Standard Shipments Investigated

Scenario	Transportation Mode				
	Truck	Van*	Pass. Air	Cargo Air	Rail
Tc^{99m}	0	38,000	38,000	0	0
Mo - Tc Gen.	17,600	32,800	16,400	16,400	0
I^{131}	6,370	57,100	33,300	23,800	0
Ir^{192} (100 curies)	6,600	0	0	0	0
Ir^{192} (5000 curies)	0	130	0	130	0
PuO_2	241	129	0	129	0
Mo^{99} source mat.**	7200	0	0	7200	0
I^{131} source mat.	0	1000	0	1000	0
Spent Fuel	54	0	0	0	326
RAPH (small)	4,470.0	40,000.0	23,300.0	16,700.0	0.0
RAPH (large)	0.0	2,700.0	2,700.0	0.0	0.0

*Van is used as a secondary mode for shipments by air and rail

**Truck is used as a secondary mode for shipments of Mo^{99} source material

TABLE V-10

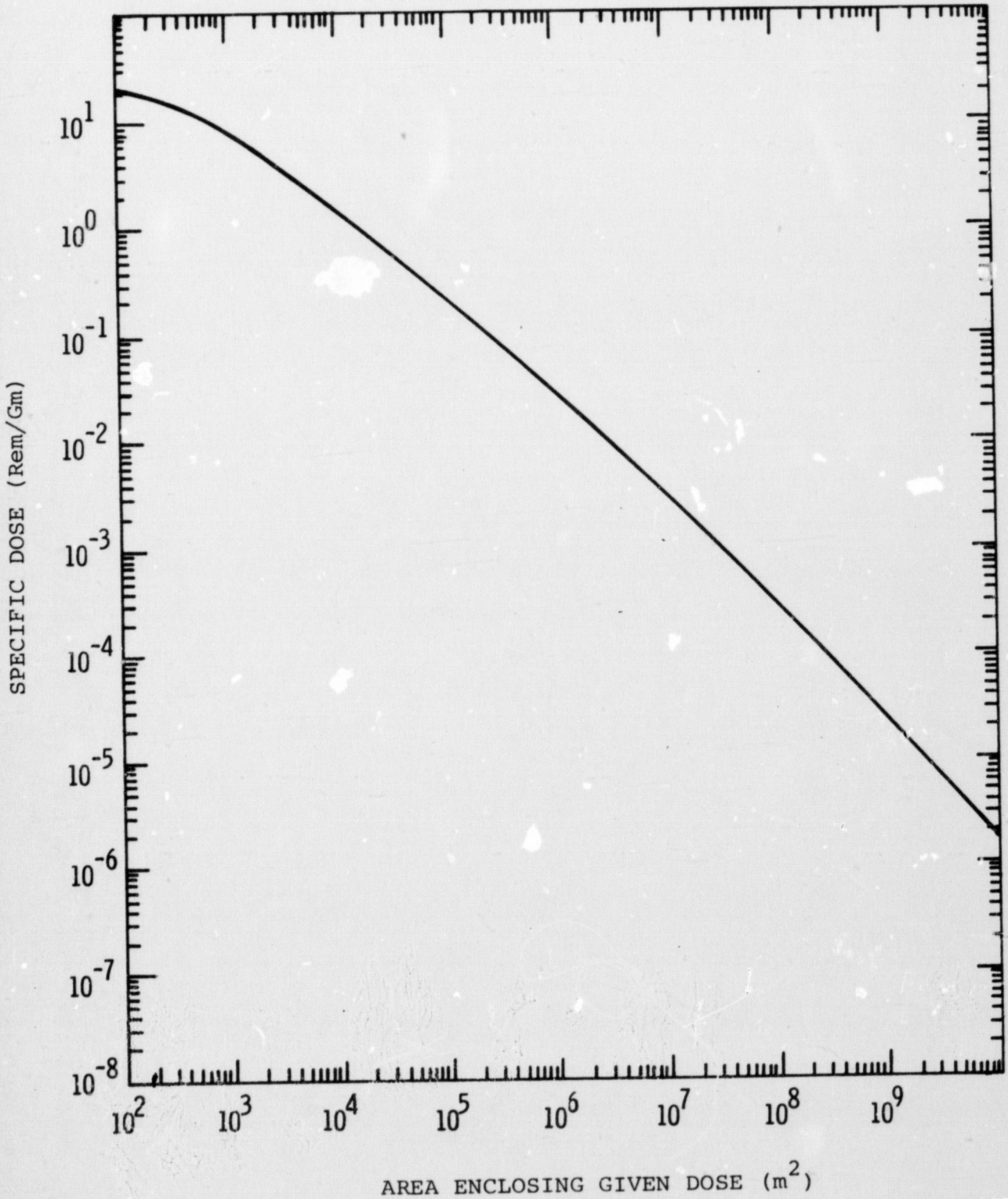
Miles Per Shipment for the Standard Shipments Investigated

Scenario	Transportation Mode				
	Truck	Van	Pass. Air	Cargo Air	Rail
Tc^{99m}	0	50	1000	0	0
Mo - Tc Gen.*	600	50 200**	1000	1000	0
I^{131}*	600	50 200**	1000	1000	0
Co^{60} (100 curies)	1000	0	0	0	0
Co^{60} (5000 curies)	0	50	0	1000	0
PuO_2	1200	50	0	1200	0
Mo^{99} source mat.	250	0	0	1000	0
I^{131} source mat.	0	50	0	1000	0
Spent Fuel	1000	0	0	1000	0
RAPH (small)*	600	50 200**	1000	1000	0
RAPH (large)	0	50	0	1000	0

*These materials go by truck, by cargo air and van, and by passenger air and van.

**If cargo air is used in addition to passenger air, secondary line (i.e., van) is longer than if passenger air is used exclusively since all major airports do not have air cargo service.

Figure V-11. Specific Dose vs. Area. Specific dose in rem per gram of respirable plutonium-239 released to the atmosphere as a function of the exposed area (in meters squared) of the earth's surface.



result of computer code output) in terms of plutonium-239 50-year lung dose per gram of dispersed inhalable plutonium aerosol. The contribution to the total dose from cloudshine, groundshine, and resuspension can be obtained by the application of established factors to the results shown in Figure V-11. For plutonium-239 and the other isotopes of interest, these radiation effects are negligible (see Figures VI-13-1 through VI-13-14 in Appendix VI to Reference 15).

In order to evaluate the impact of isotopes other than Pu-239, the results presented in Figure V-11 were divided by the rem per gram of Pu-239 inhaled in order to obtain a value for grams inhaled per gram released. This value reflects only the dilution produced by transport and diffusion of the aerosol cloud. This dilution factor is then multiplied by (1) the appropriate rem/curie values for the material released (Table V-11), (2) the quantity (in curies) of respirable material released and (3) a factor which accounts for the fact that a distribution of particles of various sizes is inhaled while the values in Table V-11 are for 1 μm diameter particles. The product of these four factors is the dose in rem for the nuclide of interest and the corresponding affected area.

The second factor shown above, the quantity of respirable material produced, is represented as follows:

Pespirable Aerosol Released = Total Package Contents x Fraction Aerosolized x Fraction Respirable

The fraction aerosolized for solid materials other than plutonium was approximated using techniques suggested in Reference 16, using vapor pressures from Reference 17. All

materials transported in powder, liquid or gaseous form were assumed to be 100 percent aerosolized. Nondispersible radioactive materials such as Co-60 and Ir-192 in special form were assumed to pose only a direct radiation hazard as a result of their gamma radiation. That this is an upper limit value is clear, but the fraction aerosolized is likely to be very sensitive to the details of an accident and no suitable data base or analysis technique provides a defensible lower value.

The fraction respirable is obtained from particle size distribution of the aerosols formed when t e material of interest is dispersed. Gases are assumed to be 100 percent respirable as are other materials when no contradictory information was available. For plutonium, a material of special emphasis in this accident risk analysis, particle size distribution are available.[18] Plutonium is frequently shipped (in the nuclear fuel cycle context) in the form of an oxide powder. The size distribution of the material is not uniquely defined and is a function of the production process used. Figure V-12 shows the range of sizes which is obtained from the same process at two different calcining temperatures.

Particles of plutonium oxide with diameters smaller than 3.3 micrometers are normally considered to be respirable and candidates for deposition in pulmonary tissue (see Figure V-13, ρ - 10 gms/cm^3). The upper curve in Figure V-12 is a material which is about 11 percent respirable and the lower curve 4 percent respirable. A size distribution for FFTF feed material was obtained from Hanford Engineering and Development Laboratory (HEDL) which was about 20 percent respirable. Plutonium oxide shipped into the United States from Belgium

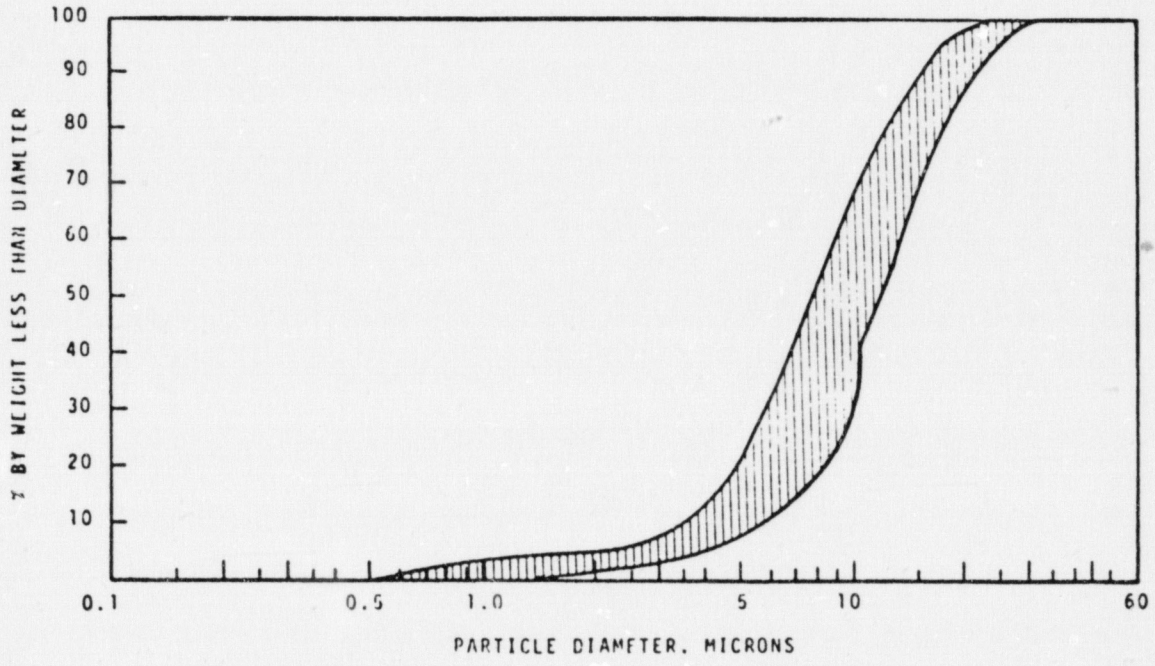


Figure V-12. Variation in Plutonium Dioxide Particle Size Distribution for a Range of Calcining Temperature Between 800 and 1200°C(19)

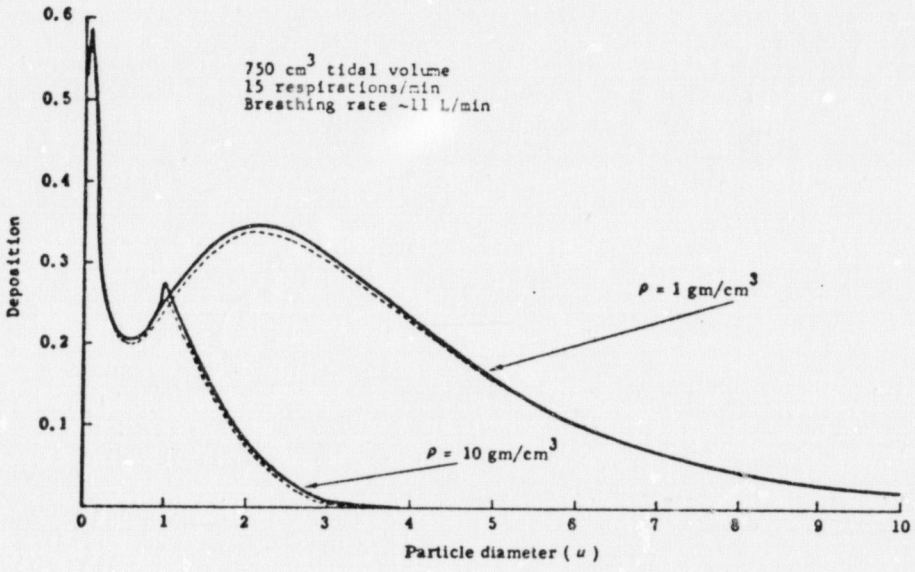


Figure V-13. Deposition in the Pulmonary Compartment vs. Particle Diameter(20)

through JFK Airport in 1974 and 1975 was reported to have a 1 μm mean size (based on surface area) which is a 40 percent respirable aerosol.*

For the purpose of this analysis a 20 percent respirable aerosol was assumed. While this is twice the upper of the values shown in Figure V-12 it is half the value for the imported material and therefore represents a conservative median value.

The third factor indicated earlier corrects for the fact that a distribution of particle sizes is likely to be released from an accident site, while the dosimetric calculation in reference 15 and Table V-11 are for particles of a size (1 to 3 μm in diameter depending on density) for which deposit in the pulmonary region is maximized. The factor is the product of two components; one is the ratio of the fraction of the inhaled aerosol which is deposited in lung to that of the idealized particles inhaled. For plutonium this fraction is approximately 11/24 or 0.46. The second component relates to the ratios of irradiation rates and clearance rates for differing size distributions of particles. This factor is approximately unity for plutonium. Using the parameters and data indicated above, the consequences for the general population were calculated for the large shipment scenarios listed in Table V-7 and are summarized in Tables V-12 and V-13. The consequences shown in Table V-12 are expressed in terms of person-rem for each of three population density areas in which an accident might occur. In urban areas where the population density is greater than 4000 persons/km^2, the impact would be

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*This assumes a log-normal size distribution with a mass median diameter of 3.3 μm and a geometric standard deviation of 3.

TABLE V-11

Summary of Rem/Curie (inhaled) Values Used to Assess the Consequences of Accidents Involving Transportation of Radioactive Materials

Radionuclide	Chemical Form	1-year Rem/curie*	Organ	50-year Rem/curie*	Organ
	Inscluble oxide	1.2×10^8	Lung	2.9×10^8	Lung
Mo-99	Insoluble molybdenate or oxide	1.6×10^4	Lung	1.6×10^4	Lung
I-131 and RAPH	Soluble iodide or iodate	$1.1 \times 10^{6**}$	Thyroid	$1.1 \times 10^{6**}$	Thyroid
Kr-85	Soluble-gas	.61	Bone marrow	.61	Bone marrow
Ir-192	Metal cylinders		Not aerosoliz-able or respirable	.61	Bone marrow
Spent fuel fission products (CS-137)	Soluble oxides	3.1×10^4	Lung	4×10^4	Lung
Tc-99m	Soluble pertechnate	89.0	Lung	89.0	Lung

*Values taken from Table III-8

**60-day dose

TABLE V-12

Worst-Case Accident Consequences in Person-Rem from
Large Shipment Scenario Accident Occurring in A Specific Population Zone

	Low	Medium	High
I^{131} (1000 ci) (thyroid dose)	1.1×10^3	1.1×10^4	1.1×10^5
Co^{60} irradiator source* (1×10^6 ci) (whole-body dose)	2.2×10^2	2.2×10^3	2.2×10^4
PuO_2 (20 Kg)			
1-yr lung dose	1.5×10^5	1.5×10^6	1.5×10^7
50-yr lung dose	2.4×10^5	2.4×10^6	2.4×10^7
Mo^{99} raw material (3000 curies)	6.5×10^1	6.5×10^2	6.5×10^3

*No shielding from buildings, vehicles, or natural surroundings are considered. The effect of such shielding will substantially reduce these values.

TABLE V-13

Consequences of Worst-Case Accidents Involving the Large Shipment Scenarios in Terms of Number of People Receiving Greater Than a Given Dose in Rem

Scenario	Integrated 1 Year Dose (Rem)	POPULATION DENSITY		
		Low	Medium	High
		2.8×10^3	2.8×10^4	2.8×10^5
20 kg Pu (lung dose)	15 Rem	0	2	16
	10,000 Rem	0	0	1
	100,000 Rem			
3000 ci Mo-99 (lung dose)	15 Rem	0	1	8
	3000 Rem	0	0	0
1000 ci I-131 (thyroid dose)	30 Rem	2	20	200
	25,000 Rem	0	0	0
10^6 ci Co-60* (1-hour whole-body exposure)	5 Rem	25	250	2500
	50 Rem	3	25	250
	340 Rem	0	4	40

*No shielding from buildings, vehicles, or natural surroundings are considered. The effect of such shielding will substantially reduce these values.

increased proportionately. Table V-13 shows the number of people likely to be exposed to doses exceeding the recommended NCRP[21] limiting values and those producing physiological effects. The significance of the doses is outlined below:

15 Rem to lungs	- NCRP recommended limit for routine exposure of radiation workers
3000 Rem to lungs	- threshold for pulmonary morbidity from short lived gamma and beta emitters[15]
10,000 Rem to lungs	- threshold for pulmonary morbidity from long lived alpha emitters[15,22]
100,000 Rem to lungs*	- produces early fatality resulting from pulmonary fibrosis and radiation pneumonitus[22] from long lived alpha emitters
30 Rem to thyroid	- NCRP recommended limit for routine exposure of radiation workers
25,000 Rem to thyroid	- threshold for radiation thyroiditis[15]
5 Rem to whole body	- NCRP recommended limit for annual whole-body radiation of radiation workers
50 Rem to whole body	- threshold for noticeable physiological effects from whole-body radiation
340 Rem to whole body*	- produces early fatality from bone marrow destruction

*LD50/360 value (lethal dose within 360 days for 50% of a population so exposed).

From Table V-12 it is clear that accidents involving PuO_2 and, to a lesser extent, Iodine-131 are observed to produce the largest consequences in terms of person-rem. Table V-13 shows that accidents involving PuO_2 and Co-60 produce the largest consequences in terms of physiological effect.

F. Results of Risk Analysis for Standard Shipments

F.1 Radiological Risks

The consequences for the standard shipments model are a function of the population density in the area in which an accident occurs. In order to assess the overall risk to the public of accidents involving radioactive material, the consequences were weighted by the appropriate scale factors to denote proportion of accidents of a given type within each population zone.

The risk for each shipment in person-rem/year was calculated using Equation 1. A summation was made over the eight accident severity categories defined previously. Both models - I and II, corresponding to different release fraction assumptions (see Table V-6), were used. The results are summarized in Tables V-14 and V-15.

The shipment involving plutonium exhibits the highest risk for accidents for both release fraction models and overshadows all other materials. Iodine-131 raw material and other radiopharmaceutical shipments account for essentially all of the remaining risk. Model II, involving more realistic release fractions than Model I, lowers the magnitude of the plutonium risk by approximately a factor of 10,000 from that

TABLE V-14

Accident Risk Analysis Results for Model I - 1975

Standard Shipments	Risk Total (Latent Cancer Fatalities)*	Percent of Total Risk
Tc^{99m}	3.3×10^{-7}	N**
Mo - Tc Generators	9.1×10^{-4}	N
I^{131}	5.9×10^{-4}	N
Ir^{192} (100 curies)	6.9×10^{-9}	N
Ir^{192} Raw Material	9.4×10^{-10}	N
PuO_2	6.5	99.8
Mo^{99} Raw Material	8.5×10^{-4}	N
I^{131} Raw Material	1.2×10^{-3}	N
Spent Fuel		
Kr^{85}	8.0×10^{-8}	N
I^{131}	5.5×10^{-5}	N
Fission Products	1.3×10^{-3}	N
RAPH (small)	1.4×10^{-3}	N
RAPH (large)	4.4×10^{-3}	N

*These fatalities are those that will result from radiation exposure during the given year due to transportation accidents.

**Negligible

TABLE V-15

Accident Risk Analysis Results for Model II - 1975

Standard Shipments	Risk Total (Latent Cancer Fatalities)*	Percent of Total Risk
Tc^{99m}	8.0×10^{-10}	N**
Mo - Tc Generators	7.3×10^{-7}	N
I^{131}	8.5×10^{-7}	N
Ir^{192} (100 curies)	3.4×10^{-13}	N
Ir^{192} Raw Material	6.5×10^{-13}	N
PuO_2	5.5×10^{-4}	98.7
Mo^{99} Raw Material	2.7×10^{-7}	N
I^{131} Raw Material	8.5×10^{-7}	N
Spent Fuel		
Kr^{85}	4.3×10^{-12}	N
I^{131}	2.9×10^{-9}	N
Fission Products	7.0×10^{-8}	N
RAPH (small)	2.1×10^{-6}	0.4
RAPH (large)	3.0×10^{-6}	0.5

*These fatalities are those that will result from radiation exposure during the given year due to transportation accidents.

**Negligible

predicted using the very conservative assumptions based on regulatory requirements for packages.

Projections of the shipments of radioactive material in 1985 were made (see Chapter I-D). These estimates allowed calculation of the expected risk due to accidents in 1985 allowing for the projected increase in curies shipped. The risks for the standard shipments model in 1985 are set out in Tables V-16 and V-17 for Models I and II, respectively. The person-rem/year risk increases in the 1985 projections are in accord with the expected increase in shipping activities. The percentage of risk due to accidents involving plutonium goes down slightly; whereas the percentage of risk due to radiopharmaceuticals increases slightly.

F.2 Non-Radiological Risks in Transportation Accidents

Most radioactive materials are shipped incidentally to other freight shipments; i.e., the shipment would take place whether or not the radioactive material were on board. The only additional risk involved in these radioactive material shipments is a radiological one.

However, for sole-use shipments, i.e., those which require the exclusive use of the transport vehicle, there are certain non-radiological risks which must also be considered, e.g., the risk that the driver of a sole-use vehicle will be injured or killed in an accident not from radiological causes, but from the impact of the accident itself. These non-radiological injuries, fatalities, or property damage must be considered as part of the environmental impact of radioactive materials transport along with the radiological effects.

TABLE V-16

Accident Risk Analysis Results for Model I - 1985

Standard Shipments	Risk Total (Latent Cancer Fatalities)*	Percent of Total Risk
Tc^{99m}	8.6×10^{-7}	N**
Mo - Tc Generators	2.4×10^{-3}	N
I^{131}	1.5×10^{-3}	N
Ir^{192} (100 curies)	1.8×10^{-8}	N
Ir^{192} Raw Material	2.5×10^{-9}	N
PuO_2	12.0	99.6
Mo^{99} Raw Material	2.2×10^{-3}	N
I^{131} Raw Material	3.2×10^{-3}	N
Spent Fuel		
Kr^{85}	7.6×10^{-7}	N
I^{131}	5.2×10^{-4}	N
Fission Products	1.3×10^{-2}	0.1
RAPH (small)	3.7×10^{-3}	N
RAPH (large)	1.1×10^{-2}	0.1

*These fatalities are those that will result from radiation exposure during the given year due to transportation accidents.

**Negligible

TABLE V-17

Accident Risk Analysis Results for Model II - 1985

Standard Shipments	Risk Total (Latent Cancer Fatalities)*	Percent of Total Risk
Tc^{99m}	2.1×10^{-9}	N
Mo - Tc Generators	1.9×10^{-6}	0.2
I^{131}	2.2×10^{-6}	0.2
Ir^{192} (100 curies)	8.8×10^{-13}	N
Ir^{192} Raw Material	1.7×10^{-12}	N
PuO_2	1.1×10^{-3}	98.1
Mo^{99} Raw Material	7.1×10^{-7}	N
I^{131} Raw Material	2.2×10^{-6}	0.2
Spent Fuel		
Kr^{85}	4×10^{-11}	N
I^{131}	4.6×10^{-8}	N
Fission Products	6.7×10^{-7}	0.1
RAPH (small)	5.4×10^{-6}	0.5
RAPH (large)	7.8×10^{-6}	0.7

*These fatalities are those that will result from radiation exposure during the given year due to transportation accidents.

It has been estimated[23] that transport of cold fuel to nuclear power plants and shipments of irradiated fuel and solid wastes from the plants by sole-use vehicles could result in .03 injuries and .003 fatalities per reactor year, if all fuel and solid waste transport were by truck and irradiated fuel transport were by rail or barge. For the approximately 60 power reactors in operation in 1975 this translates into 2 injuries and 0.2 fatalities per reactor year.

Probably the greatest use of sole-use trucks for other than fuel cycle materials is in the transport of radiopharmaceuticals, primarily Mo-99/Tc-99m generators. If it is estimated that 10 percent of the generators that travel by truck in the standard shipments model (Mo-99 small) are transported by sole-use trucks in average aggregate quantities of 80 TI per shipment, then about 100 such shipments per year would be expected. For an average shipment distance of 600 miles, the total distance traveled would be 6×10^4 miles per year. Utilizing the accident statistics and injury and fatality data which was used to estimate the non-radiological impact for shipments to and from power plants,[21] the transport of Mo-99/Tc-99m generators by sole-use trucks would produce about 0.05 injuries and about .003 fatalities per year.

Finally, certain all-cargo airlines make routine flights exclusively for shipment of radioactive materials, primarily Mo-99/Tc-99m generators. It is estimated that these flights cover 200,000 miles per year. Using the cargo aircraft accident rates of 5.6×10^{-8} accidents per mile, these flights would be expected to result in about 0.01 accidents per year. Assuming that a crew of two would be killed in

each accident, an average of 0.02 fatalities per year would be expected.

Thus, the estimated non-radiological impacts resulting from transport of radioactive material in sole-use vehicles amounts to 2.05 injuries and .223 fatalities per year. The major contribution is made by transport of cold and spent fuel to and from nuclear power plants.

G. Comparison to Other Risks

In order to compare the risk of accidents involving radioactive material with other risk situations, a calculation of early fatality probability was performed for the 1975 standard shipments model.

The computation of the number of fatalities expected from a given accident starts with the Gaussian dispersion results illustrated in Figure V-11. From the graph, the number of people within an area who receive a specific dose can be determined for a given source term. In order to compute the probability of early fatalities based on the number of people exposed in the dose isopleth, the binomial approach is used.

$$P_k = \binom{n}{k} P_2^{\,k} (1 - P_2)^{n-k} \qquad (2)$$

where k = number of deaths under consideration

P_k = probability of k fatalities within an area of specific dose

P_2 = probability that a given dose will be fatal

n = number of people in the area

Equation (2) is used 5 times for areas with fatality probabilities (P_2) of .01, .05, .1, .5, and 1.0. These results are combined to yield (Equation 3) the probability of k fatalities from a given dose distribution.

$$P_3 = 1 - \prod_{i=1}^{5} (1 - P_i)_i \qquad (3)$$

where P_3 = probability of k or more fatalities from a given dose distribution

P_i = probability of k or more fatalities in the ith dose area

The values computed in (3) must be combined with the probability of an accident which might yield that dose distribution. The Poisson distribution,

$$P(\text{x discrete occurrences}) = \frac{\lambda^x e^{-\lambda}}{x!} \qquad (4)$$

is used with λ equal to the accident rate for a given severity accident. Thus,

$$P_4 = P_3 \cdot P_{\ell,m} \qquad (5)$$

where P_4 = the probability of k fatalities per year from accidents of a specific severity in a specific population zone

$P_{\ell,m}$ = probability of a given severity accident ($1 \leq \ell \leq 8$) in a given population zone ($1 \leq m \leq 3$)

The value computed in (5) is then combined over all accident severities and population zones using equations similar to Equation (3). The results of this calculation are shown in Table V-18 for the four standard shipment-release fraction combinations considered here.

From the tabulated results it is clear that the probability of of early fatalities in the normal run of radioactive material shipping is quite small. For comparison, the results for Model-1985 and Model I are shown, together with other risks of early fatality in Table V-19

The risk of any fatality-producing event can be expressed in terms of the chances that any specific individual will be killed by the event in a year. This table is predicated on two assumptions: (1) events such as those listed, occur at random throughout the population (2) the population in the U. S. at risk is about 75,000,000 people. The individual risk of early fatality due from radiological causes due to transportation of radioactive material is quite small in comparison to the other risk situations listed including the risk of fatality from aircraft or motor vehicle accidents.

TABLE V-18

Probability per Year of Early Fatalities from Radiation Effects Resulting from Radioactive Material Shipments

Number of Fatalities	Model II - 1975	Model I - 1975	Model II - 1985	Model I - 1985
1	7.4×10^{-8}	1.1×10^{-2}	8.2×10^{-8}	1.1×10^{-2}
2	0	1.9×10^{-4}	0	1.9×10^{-4}
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
10	0	0	0	0
20	0	0	0	0

TABLE V-19

Individual Risk of Early Fatality By Various Causes[13]

Accident Type	Number Per Year	Individual Risk Per Year
Motor Vehicle	5.5×10^{4}	1 in 4,000
Falls	1.8×10^{4}	1 in 10,000
Fires	7.5×10^{3}	1 in 25,000
Drowning	6.2×10^{3}	1 in 30,000
Air Travel	1.8×10^{3}	1 in 100,000
Falling Objects	1.3×10^{3}	1 in 160,000
Electrocution	1.1×10^{3}	1 in 160,000
Lightning	160	1 in 2,000,000
Tornadoes	91	1 in 2,500,000
Hurricanes	93	1 in 2,500,000
100 Nuclear Reactors	3×10^{-3}*	1 in 5,000,000,000
Transportation of Radioactive Material (from Radiological causes)	7.4×10^{-8}**	1 in 1,000,000,000,000,000***

*Statistical Estimate

**Statistical Estimate for 1975

***Using a population at risk of 75 million people

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CHAPTER VI

ALTERNATIVES

A. Introduction

The National Environmental Protection Act (NEPA) sets standards for the preparation of environmental impact statements and requires the consideration of alternatives to the action or activity whose environmental impact is being assessed. The analysis of the impact of transportation of radioactive materials presented in Chapter I through V was concerned with current shipping practices and their 1985 projections. In this chapter the environmental impacts of alternatives are considered and are compared to the impacts resulting from current shipments. An alternative which results in a lower annual population dose is desirable from a radiological point of view, but may not be considered worthwhile when the cost of implementation and the non-radiological impacts are considered. Similarly, one alternative may be desirable from a safeguards viewpoint but undesirable from a radiological viewpoint. Thus, a quantitative comparison of the radiological impacts may be made in terms of the number of excess latent cancer fatalities (LCF) produced, but an assessment of the total impact of a given alternative upon the environment must include qualitative consideration of other factors.

The environmental impact of an alternative in radioactive materials shipments is meaningful only when compared to the impact of the current shipping practice. Consequently, the results of the assessments of the alternatives considered in this chapter are presented in terms of the environmental impacts relative to the baseline case of current shipments. Table VI -1 summarizes the results of the risk analysis

TABLE VI -1. Summary of Radiological Impacts of Current Shipments

Standard Shipment	Annual-Pop. Dose-Normal Trans. (Person-rem)	Annual-Pop. Dose-Normal Trans. Latent Cancer Fatalities	Annual-Pop. Dose due to Accidents Organ	Annual-Pop. Dose due to Accidents Latent Cancer Fatalities
Tc-99m	171	.021	Lung	8.0×10^{-10}
Iodine-small	2779	.338	Thyroid	8.5×10^{-7}
Iodine-large	16	.002	Thyroid	8.5×10^{-7}
Mo-99-small	4240	.55	Lung	7.3×10^{-7}
Mo-99-large	299	.036	Lung	2.7×10^{-7}
RAPH-small	1217	.148	Thyroid	2.1×10^{-6}
RAPH-large	46	.006	Thyroid	3.0×10^{-6}
Ir-192-source	248	.030	Whole body	3.4×10^{-13}
Ir-192-raw material	5	.001	Whole body	6.5×10^{-13}
Spent Fuel	535	.065	Thyroid, Lung, Bone Marrow	7.3×10^{-8}
$Pu-O_2$	33	.004	Lung, Bone	5.5×10^{-4}
TOTAL	9589 (9600)	1.166 (1.2)		5.58×10^{-4} (5.6×10^{-4})

described in Chapters IV and V for the normal and accident cases, respectively, and is used as the baseline for comparison of the risk assessment of the alternatives. As indicated in the table, the total number of LCF that would be expected to be produced as a result of radioactive materials transport for one year with current shipping rates and practices is 1.2 for normal transport and 5.6×10^{-4} resulting from transportation accidents involving radioactive material.

Where appropriate, the cost of implementing an alternative is estimated, and this cost is compared to the benefit resulting from the alternative. Benefits are expressed in terms of the estimated reduction in annual LCF resulting from implementation of the alternative. To compare benefits to costs it is necessary to assign a monetary value to an LCF. For the purposes of this assessment the official NRC figure[1] of $1000 per person-rem is used along with the whole-body dose effect value[2] of 121.6 LCF/10^6 person-rem, resulting in a value of $\$8.22 \times 10^6$ for one LCF.

The alternatives to be discussed in this chapter may be classified into two general types:

a. transport mode shifts
b. operational and packaging constraints

Transport mode shifts involve additional or alternative regulations which would eliminate the use of certain transport modes either for all radioactive material shipments or for certain of the potentially more hazardous isotopes, e.g., plutonium. The assumption is made in the evaluation of the effects of these mode shifts that the material(s) involved would continue to be transported in the same total annual quantities, but by a different mode.

The alternatives of the second type considered in this chapter are those which would:

a. require the use of specific transport vehicles with better than average safety records.
b. require specific operational constraints on transport to limit accident rates or consequences, e.g. route restrictions, the restriction of hazardous materials flights to good weather and daytime only, lower speed limits for surface modes, special crew training, no weekend driving, and use of specific airports.
c. restrict the form of the material shipped to reduce its dispersibility and/or respirability in the case of an accident severe enough to breach the packaging.
d. reduce the quantity of material shipped on a given transport vehicle to reduce the amount which could be dispersed in a severe accident.
e. require the use of extra-durable packaging for shipments involving Type B and large quantities of the potentially more hazardous isotopes. This could be accomplished by the introduction of new packaging standards.
f. lower the package quantity limits or package TI limits.

Each of these general alternative types is discussed in detail in Section B of this chapter. Risk estimates are made and are compared to the risks due to current shipments. Section C summarizes the results for all alternatives.

B. Survey of Specific Alternatives

B.1 Mode Shifts

In this section the effects expected from shifting of various classes of radioactive material from one transport mode to another is assessed. Those combinations which seemed likely to yield a decrease in radiological impact, those which seemed effective in increasing security, and those which might decrease accident risk to the public are considered.

B.1-1 All Air Transport by Truck

As of July 1, 1975 the materials transported by aircraft consisted principally of radiopharmaceuticals and the raw materials from which they are made, plutonium, and some irradiator source materials (see Table VI -2). The result of shifting this material to trucks was evaluated by increasing the number of truck shipments in the standard shipment list by the baseline number of aircraft shipments of each radionuclide. In addition, the miles travelled per shipment was increased slightly to account for the fact that truck transport is often less direct than air transport. The standard shipments model revisions for this mode shift are shown in Table VI -3.

Also reflected in the standard shipments list for this alternative are increased values of package TI's which result from differences in transport speed between the air and the truck mode. It would be necessary for somewhat greater quantities of short half-life materials to be sent in order to insure that the required radioactivity is present in the material at the time of treatment.

TABLE VI -2. Baseline Shipment Information

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO2 →	3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBNATE
MO99 SMALL	.600	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	58.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	0.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.83E+04	3.83E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	6.37E+03	3.33E+04	3.33E+04	2.38E+04	0.	0.	2.38E+04	0.	0.
IR192 SOURC	6.80E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO2 →	2.60E+02	0.	0.	1.12E+02	0.	0.	1.12E+02	0.	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.70E+04	1.64E+04	1.64E+04	1.64E+04	0.	0.	1.64E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH.SMALL	4.47E+03	2.33E+04	2.33E+04	1.67E+04	0.	0.	1.67E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	500	50	1000	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO2 →	1200	0	0	1200	0	0	50	0	0
MO99 LARGE	500	0	0	1000	0	0	0	0	0
MO99 SMALL	500	50	1000	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH.SMALL	600	50	1000	1000	0	0	200	0	0

TABLE VI -3. All Air Shipments by Truck

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO2	3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBNATE
MO99 SMALL	.800	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	56.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	BARGE	HELICOPTER	AIR TAXI
TC-99M	3.80E+04	0.	0.	0.	0.	0.	0.	0.	0.
I131 SMALL	6.35E+04	0.	0.	0.	0.	0.	0.	0.	0.
IR192SOURC	6.65E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	1.30E+02	0.	0.	0.	0.	0.	0.	0.	0.
PuO2	3.72E+02	0.	0.	0.	0.	0.	0.	0.	0.
MO99 LARGE	7.20E+03	0.	0.	0.	0.	0.	0.	0.	0.
MO99 SMALL	5.04E+04	0.	0.	0.	0.	0.	0.	0.	0.
I131 LARGE	1.01E+03	0.	0.	0.	0.	0.	0.	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	0.	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	0.	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	0.	0.	0.
RAPH.LARGE	2.70E+03	0.	0.	0.	0.	0.	0.	0.	0.
RAPH.SMALL	4.45E+04	0.	0.	0.	0.	0.	0.	0.	0.

MILES PER SHIPMENT

TC-99M	1000	0	0	0	0	0	0	0
I131 SMALL	1000	0	0	0	0	0	0	0
IR192SOURC	1000	0	0	0	0	0	0	0
IR192 R.M.	1000	0	0	0	0	0	0	0
PuO2	1200	0	0	0	0	0	0	0
MO99 LARGE	1250	0	0	0	0	0	0	0
MO99 SMALL	1000	0	0	0	0	0	0	0
I131 LARGE	1000	0	0	0	0	0	0	0
SFKR	1000	0	0	0	1000	0	0	0
SFI	1000	0	0	0	1000	0	0	0
SFFP	1000	0	0	0	1000	0	0	0
RAPH.LARGE	1000	0	0	0	0	0	0	0
RAPH.SMALL	1000	0	0	0	0	0	0	0

It is estimated that the minimum time required from shipment to use is approximately 20 hours (essentially overnight) by the air mode for shipments within the continental United States. In a similar time period destinations within 200-300 miles could be served by truck with no additional radioactive material required to compensate for the loss resulting from radioactive decay. However, for longer distances, shipments must contain more radioactivity at the time of shipment. The amount required can be estimated using the following relation:

$$\frac{A_t}{A_a} = \exp\left[0.693(x/u - 20)/t_{1/2}\right] \left(\frac{x}{u} \geq 20\right) \qquad (1)$$

where A_t = initial activity for truck shipment (curies)

A_a = initial activity for air shipment (curies)

x = destination distance from shipper (mi)

u = mean transport speed for trucks (mph)

$t_{1/2}$ = nuclide half-life (hrs)

Using a mean transport speed of 29 mph (12.5 mph for 250 miles and 55 mph for 750 miles) and a distance of 1000 miles, it is found that A_t/A_a is 1.1 or greater when $t_{1/2}$ is 115 hrs (4.75 days) or less. Thus package activity is likely to be increased significantly only for nuclides having half lives shorter than this value. Of the specific nuclides included in the standard shipments model only Tc-99m and Mo-99 have shorter half lives. Of the radiopharmaceuticals included under RAPH only Au-198 (65 hours), F-18 (.18 hours), Ga-67 (78 hours), Hg-197 (65 hours), In-111 (67 hours) and Rb-81 (4.7 hours) have shorter half lives. These nuclides

account for about 10 percent of the total activity included in RAPH. For these nuclides the following A_t/A_a values are obtained using equation (1) for a shipment of 1000 miles:

	Nuclide	A_t/A_n	$(TI)_t/(TI)_a$
	Tc-99 M	6.2	6.2
	Mo-99	1.18	1.18
RAPH	Au-198	1.18	1.095
	F-18	420	
	Ga-67	1.15	
	Hg-197	1.18	
	In-111	1.18	
	Rb-81	10.1	

To assess the impact of the larger package loading it is assumed that no increase in shielding is used unless the increased loading would increase the package transport index to greater than 3 TI (an effective maximum value for passenger aircraft shipments). In that case, it is assumed that sufficient shielding is added to limit the transport index to 3. Since the F-18 packages are the only ones that would require increased shielding, the extra costs to the industry would be negligible.

B.1-1.1 Radiological Impacts

The resulting changes in radiological impact obtained from this mode shift are shown in Table VII-4. The overall result is an increase in the total person-rem from normal transport and a decrease in that resulting from accident occurrence. Although the aircraft passenger dose is

reduced to zero, the dose accumulated during the surface transport of the shifted material is increased, giving a net increase of about 33 percent in the radiological impact.

For the accident case, the decrease in radiological impact is directly related to the decreased probability of experiencing accidents in truck transport of sufficient severity to breach plutonium and large I-131 Type B packaging. As a result, the latent cancer fatalities resulting from accidents decrease.

Table VI -4. Summary of Results for All Air Shipments by Truck

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.557	+33%
Normal Transport (annual person-rem)	9589	12810	+33%
Accidents L.C.F.	5.59×10^{-4}	4.39×10^{-4}	21% decrease
Probability of ≥ 1 Early Fatality per Year	7.40×10^{-8}	6.20×10^{-8}	16% decrease

B.1-1.2 Non Radiological Impacts

The shift of all radioactive materials from an air mode to truck mode implies an increase in truck shipments from 4.3×10^{4} to 2.1×10^{5} shipments per year or approximately a factor of 5. The total number of truck trips per year is approximately 10^{8} according to the American Trucking Association.(3) Recognizing that more than one shipment could be carried on a single truck trip, it is clear that the number of truck trips which carry radioactive material shipments is

at most 0.2 percent. Therefore, the truck transport system would be able to handle the additional traffic loads. This information also supports the contention made in an earlier chapter that radioactive materials are carried incidentally to the general run of freight transport, and a pro rata share of resource use by the industry is not readily chargeable to radioactive material transport.

Cost comparison of a mode shift from air to truck hinges on the timeliness of transport and on the basic cost of transporting a package in each mode. The increased initial loading of short half-life materials, in addition to imposing a radiological impact, also produces a cost penalty. Estimates of the incremental cost of this increased material are based on retail cost figures obtained from radiopharmaceutical supplier catalogues. The figures used are shown in Table VI -5. The actual costs to the supplier are estimated to be 50 percent of the retail costs. The total annual additional cost is obtained by multiplying the incremental cost in dollars/Ci times the number of additional curies required for shipment by the truck mode. The latter quantity is computed by multiplying the number of curies per year shifted from air to truck by the factor $\left[A_t/A_a - 1\right]$.

To evaluate differences in costs between truck and aircraft transportation the following data was obtained from Albuquerque, New Mexico offices of airline and truck transport which operate on a national scale.

Freight Rates for 1000 Mile Trip

Truck	Air
$.1177/lb. (<2000 lb.)	$.32/lb. (<100 lb.)
$.1083/lb. (2000-5000 lb.)	$.241/lb. (100-1000 lb.)
$.0559/lb. (Truckload)	$.1905/lb. (1000-3000 lb.)

TABLE VI -5

Incremental Cost in Extra Isotopic Material at Retail Prices[4]

Nuclide	At/Aa	Total Curies Baseline	Total Curies Alternative	Retail Incremental Cost ($/mCi)	Total Retail Incremental Cost/yr ($/yr)
Tc-99m	6.2	3.2×10^4	2×10^5	2	3.36×10^8
Mo-99	1.18	6.05×10^4	7.1×10^4	1.30	1.4×10^7
Au-198, F-18, Ga-67, Hg-197, In-111, Rb-81	RAPH 1.095	5602	6134	6 to 12	3.2×10^6 to 6.4×10^6
				TOTAL	$360,000,000*

*Total annual cost to supplier estimated to be half this value.

Only the inter-city fraction of the trips are of interest, since it is assumed that the secondary mode segment of either air or its truck replacement are virtually identical. The incremental cost resulting from truck transport in place of air transport is shown in Table VI-6. The net savings in actual transportation is small compared to the cost of the extra radioactive material required to make up that lost by radioactive decay in the slower truck mode. The net additional cost for transporting by truck all radioactive materials normally transported by air is $\$180 \times 10^6$. There is no cost benefit trade-off in this case, since the alternative results in both an increase in population dose and an increase in cost.

B.1-2 All Passenger Air Transport by All Cargo Air

The second option to be considered shifts radioactive material carried as cargo in passenger aircraft to all cargo aircraft. The standard shipments for this alternative are shown in Table VI -7. By comparison with Table VI -2 the following changes are evident:

a. Shipments by passenger air have been deleted and the shipments have been reassigned to cargo air.
b. The mileage for secondary modes associated with cargo air shipments has been increased to 200 miles to account for the more limited coverage of United States areas by air freight handling facilities compared to passenger facilities.

The mode shift described in this alternative may not be readily achievable without shifting some shipments entirely to the truck mode, but for the purposes of this comparison, that possibility will not be considered. Rather it is assumed that the required coverage can be achieved by the "package airfreight lines" which have begun to serve many parts of the

TABLE VI -6

Transportation Costs - Air Transported Materials by Truck

Material	Weight	Nc./yr	Miles/Shipment	Freight Cost per Shipment		Annual Air Cost-Truck Cost in Dollars
				Truck	Air	
Tc-99m	15	3.8×10^4	1000	11.77	14.00	8.5×10^4
I-131 small	15	5.7×10^4	1000	11.77	14.00	1.3×10^5
Ir-192 R.M.	1000	1.3×10^2	1000	117.70	200.0	1.1×10^4
Plutonium	100	1.12×10^2	1200	20.00	45.00	3.4×10^3
Mo-99 large	1000	7.2×10^3	1000	117.70	200.00	5.9×10^5
Mo-99 small	140	3.28×10^4	1000	11.77	22.40	3.5×10^5
I-131 large	500	$1. \times 10^3$	1000	58.85	125.00	6.6×10^4
RAPH large	500	2.7×10^3	1000	58.85	125.00	1.8×10^5
RAPH small	15	4.0×10^4	1000	11.77	14.00	8.9×10^4
					TOTAL	1.5×10^6

*Cost per 1000 mile trip, except for plutonium, where the cost is given for a 2000 mi trip.

TABLE VI -7. All Passenger Air Shipments by All Cargo Air

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.3E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	500.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO_2	3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBNATE
MO99 SMALL	.600	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	56.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	0.	0.	3.80E+04	0.	0.	3.80E+04	0.	0.
I131 SMALL	6.37E+03	0.	0.	5.71E+04	0.	0.	5.71E+04	0.	0.
IR192 SOURC	6.50E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO_2	2.60E+02	0.	0.	1.12E+02	0.	0.	1.12E+02	0.	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.76E+04	0.	0.	3.28E+04	0.	0.	3.28E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH.SMALL	4.47E+03	0.	0.	4.00E+04	0.	0.	4.00E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	0	0	1000	0	0	200	0	0
I131 SMALL	600	0	0	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO_2	1200	0	0	1200	0	0	50	0	0
MO99 LARGE	250	0	0	1000	0	0	0	0	0
MO99 SMALL	600	0	0	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH.SMALL	600	0	0	1000	0	0	200	0	0

United States. It should be noted that a shift to package airfreight will involve transport in smaller aircraft, which statistically have higher accident rates. Exposure to crew members will also increase due to the smaller aircraft dimensions.

No significant increase in package curie content has been postulated in this alternative to account for increased time between shipment and use. While it is expected that shipment will be slightly slower, the effect is not expected to be significant because the ground transport link is limited to 200 miles.

B.1-2.1 Radiological Impacts

The changes in radiological impacts resulting from adopting this alternative are shown in Table VI -8. The increase in overall person-rem and latent cancer fatalities again results from two counteracting changes. A decrease in population dose is achieved by the removal of dose to passengers, but this is offset by an increased dose resulting from increased mileage in the secondary transport mode. In spite of the fact that the accident rate for cargo aircraft is approximately three times that for passenger aircraft, the impact of this alternative upon the accident risk is small, because the material transferred from the passenger air to the cargo air mode is a minor contributor to the total accident risk.

B.1-2.2 Non-Radiological Impacts

There are no significant non-radiological impacts from this alternative other than the possibility of increased costs required to serve outlying cities by package airlines. Some scheduling difficulties are likely as a result of fewer flights of air freighters as compared to passenger aircraft. As in the previous alternative, no additional resource use is likely.

Table VI -8. Summary of Results for All Passenger Air to All Cargo Air

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.392	+19%
Normal Transport (annual person-rem)	9589	11450	+19%
Accidents L.C.F.	5.59×10^{-4}	5.61×10^{-4}	0
Probability of $\geq$ Early Fatality per year	7.40×10^{-8}	7.40×10^{-8}	0

As in the previous alternative, there is no cost-benefit trade-off, since the alternative results in an increase in population dose and in a possible increase in transport costs.

B.1-3 All Cargo Air by Passenger Air

This alternative is the opposite to that previously discussed. Shifting radioactive materials now carried on all cargo aircraft to passenger aircraft affects a wide variety of materials, ranging from medical use isotopes to well-logging sources and raw material shipments for the radiopharmaceutical industry. Table VI -9 shows the changes in the standard shipments to accommodate this alternative. In contrast to the previous case, the material shifted to passenger-carrying aircraft travels a shorter distance in a secondary mode because of the greater coverage by passenger flights of areas within the United States. In Table VI -9 the shifting of shipments from cargo to passenger air is shown as complete, but it is possible that certain large shipments such as Ir-192 raw materials might not be accommodated in the cargo holds of passenger aircraft. It is likely, therefore, that the changes in radiological impact are an upper limit to what might occur if this alternative were instituted.

TABLE VI -9. All Cargo Air Shipments by Passenger Air

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.9DE+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO_2	3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBDATE
MO99 SMALL	.600	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	55.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+05	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.10 +06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.80E+04	3.80E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	5.37E+03	5.71E+04	5.71E+04	0.	0.	0.	0.	0.	0.
IR192 SOURC	6.60E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	1.30E+02	1.30E+02	0.	0.	0.	0.	0.	0.
PuO_2	2.60E+02	1.12E+02	1.12E+02	0.	0.	0.	0.	0.	0.
MO99 LARGE	0.	7.20E+03	7.20E+03	0.	0.	0.	0.	0.	0.
MO99 SMALL	1.76E+04	3.28E+04	3.28E+04	0.	0.	0.	0.	0.	0.
I131 LARGE	0.	1.00E+03	1.00E+03	0.	0.	0.	0.	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	2.70E+03	2.70E+03	0.	0.	0.	0.	0.	0.
RAPH.SMALL	4.47E+03	4.00E+04	4.00E+04	0.	0.	0.	0.	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	600	50	1000	0	0	0	0	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	50	1000	0	0	0	0	0	0
PuO_2	1200	50	1200	0	0	0	0	0	0
MO99 LARGE	0	50	1000	0	0	0	0	0	0
MO99 SMALL	600	50	1000	0	0	0	0	0	0
I131 LARGE	0	50	1000	0	0	0	0	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	50	1000	0	0	0	0	0	0
RAPH.SMALL	600	50	1000	0	0	0	0	0	0

B.1-3.1 Radiological Impact

The changes in radiological impact are shown in Table VI -10. It is seen that the total person-rem/year resulting from normal transport is decreased by 14 percent from the baseline case. Although passenger exposure increases, a much larger decrease in exposure results from a reduction in total miles travelled in secondary modes. The accident risk is also decreased.

B.1-3.2 Non-Radiological Impact

No significant changes in non-radiological impact are expected.

Table VI -10. Summary of Results for All Cargo Air by Passenger Air

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.004	14% decrease
Normal Transport (annual person-rem)	9589	8254	14% decrease
Accidents L.C.F.	5.59×10^{-4}	4.02×10^{-4}	23% decrease
Probability of $\geq$ Early Fatality per year	7.40×10^{-8}	5.73×10^{-8}	23% decrease

The benefit in this case is a reduction in total annual L.C.F. by 0.162 L.C.F. The monetary equivalent of this reduction, as discussed in Section A of this chapter, is $\$1.3 \times 10^6$. The annual cost for the necessary additional secondary mode mileage is estimated to be $\$4.4 \times 10^6$, at 13 cents per mile for vehicle operation and $6 per hour for driver's salaries. Thus, the alternative costs are higher than those of the baseline case.

B.1-4 All Cargo Air Shipments by Truck

In this alternative all cargo air shipments are transferred to the truck mode. The actual mileage in the truck mode was estimated to be approximately the same as the airline miles. The time delay between shipment and use is of interest for this alternative since the shift is from a relatively fast mode to a relatively slow one. Following the same techniques used in the transfer of all air-transported material to truck produces a much smaller effect in this case, since Tc-99m, which dominated the earlier case, is not shipped by the air cargo mode. The standard shipments for this alternative are shown in Table VI -11.

B.1-4.1 Radiological Impact

The changes in radiological impact resulting from adoption of this alternative are shown in Table VI -12. For normal transport there is only a 2% increase in the total population dose. The risk from accidents decreases by a factor of 5 as a result of the reduced probability of encountering a truck accident severe enough to breach Type B packaging containing plutonium or other nuclides currently carried in cargo aircraft.

B.1-4.2 Non-Radiological Impacts

The non-radiological impacts resulting from shifting material from all cargo air to truck are chiefly economic. A cost penalty is associated with the increased quantities of material which must be added to a package in order to insure the proper radioactivity content at the point of use. Using the same cost data and analysis technique as in Section B.1-1.2 for the reduced numbers of shipments and nuclides effected in this alternative, the net cost penalty

TABLE VI -11. All Cargo Air Shipments by Truck

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.9JE+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.1JE+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+0J	1.00E+05	INSOLUBLE METAL
PuO_2	3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.1JE+04	INS MOLYBNATE
MO99 SMALL	.600	A	2	2.4E+00	2.1JE+04	SOLUBLE OXIDE
I131 LARGE	5E.700	B	1	1.6E+0J	1.1JE+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.1JE-01	GAS
SFI	2.000	CASK	1	0.	1.1JE+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.1JE+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.1JE+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.3JE+04	3.3JE+04	0.	0.	0.	0.	0.	0.
I131 SMALL	3.02E+04	3.33E+04	3.33E+04	0.	0.	0.	0.	0.	0.
IR192 SOURC	5.6JE+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	1.3JE+02	0.	0.	0.	0.	0.	0.	0.	0.
PuO_2	3.72E+02	0.	0.	0.	0.	0.	0.	0.	0.
MO99 LARGE	7.20E+03	0.	0.	0.	0.	0.	0.	0.	0.
MO99 SMALL	3.40E+04	1.64E+04	1.64E+04	0.	0.	0.	0.	0.	0.
I131 LARGE	1.0JE+03	0.	0.	0.	0.	0.	0.	0.	0.
SFKR	5.4JE+01	0.	0.	0.	3.26E+02	0.	3.25E+02	0.	0.
SFI	5.4JE+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.4JE+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	2.7JE+03	0.	0.	0.	0.	0.	0.	0.	0.
RAPH.SMALL	2.12E+04	2.33E+04	2.33E+04	0.	0.	0.	0.	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	1000	50	1000	0	0	0	0	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	1000	0	0	0	0	0	0	0	0
PuO_2	1200	0	0	0	0	0	0	0	0
MO99 LARGE	1200	0	0	0	0	0	0	0	0
MO99 SMALL	1000	50	1000	0	0	0	0	0	0
I131 LARGE	1000	0	0	0	0	0	0	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	1000	0	0	0	0	0	0	0	0
RAPH.SMALL	1000	50	1000	0	0	0	0	0	0

to the shippers is expected to be the cost for extra material required for the slower truck mode ($6.3 x 10^6/yr) offset by the transportation cost savings ($1.2 x 10^6/yr). This amounts to an increased cost of about $5.1 x 10^6/yr.

Table VI -12. Summary of Results for All Cargo Air by Truck

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.195	2% increase
Normal Transport (annual person-rem)	9589	9820	2% increase
Accidents L.C.F.	$5.59 x 10^{-4}$	$4.40 x 10^{-4}$	21% decrease
Probability of $\geq$ Early Fatality per year	$7.40 x 10^{-8}$	$6.20 x 10^{-8}$	16% decrease

Since the annual LCF and the annual cost both increase, this alternative is not cost-effective.

B.1-5 All Plutonium by Truck or by Rail

These alternatives are a possible means of reducing the accident risk which results from plutonium shipments on aircraft. Other alternatives with the same general goal but using package design changes, transport vehicle limitations, and operational constraints, are discussed later in this Chapter.

Plutonium shipments by aircraft could be shifted to any surface mode such as truck or rail without additional physical constraints. Packaging used is typically the size of 55 gallon drums or smaller and weights are a few hundred pounds or less. The material's half-life is sufficiently long that timeliness of transport is not important. However, its strategic value as weapon material means that any mode shift of plutonium (or any other Special Nuclear Material) in strategic quantities* requires careful consideration of the security required for protection against theft or sabotage. Because that aspect of the problem and the costs which it represents are discussed elsewhere,* it will not be reiterated here or for subsequent alternatives which change the mode of handling plutonium. Consideration will be confined to the radiological and non-radiological aspects of the environmental impact.

The standard shipments, as revised to account for a transfer of plutonium from cargo air to truck, are shown in Table VI -13, and for transfer from truck and cargo air to rail in Table VI -14. In the case of transfer of plutonium to truck or rail, no secondary mode transport is expected. It is reasonable to assume that either truck or rail delivery of plutonium would be direct from the shipper to the receiver.

B.1-5.1 Radiological Impact

The effects of shipping plutonium either all by rail or all by truck are negligible in the normal transport case (see Tables VI -15 and 16). In the accident case, both alternatives result in a decrease in annual L.C.F. as a result of the lower rates for severe accidents in surface transportation. The total accident risk decreases by 21% for truck and by a factor of 3 for rail.

*See discussions of Security and Safeguards, Chapter VII.

TABLE VI-13. All PuO_2 by Truck

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO_2	3628	B	1	5.0E+00	2.00E+04	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBDATE
MO99 SMALL	.600	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	58.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.80E+04	3.80E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	6.37E+03	3.33E+04	3.33E+04	2.38E+04	0.	0.	2.38E+04	0.	0.
IR192 SOURC	6.67E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO_2	3.72E+02	0.	0.	0.	0.	0.	0.	0.	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.78E+04	1.64E+04	1.64E+04	1.64E+04	0.	0.	1.64E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	5.41E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.41E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.41E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH.SMALL	4.47E+03	2.33E+04	2.33E+04	1.67E+04	0.	0.	1.67E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	500	50	1000	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO_2	1200	0	0	0	0	0	0	0	0
MO99 LARGE	250	0	0	1000	0	0	0	0	0
MO99 SMALL	500	50	1000	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH.SMALL	500	50	1000	1000	0	0	200	0	0

TABLE VI-14. All PuO_2 by Rail

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+01	1.00E+05	INSOLUBLE METAL
PuO_2	.3628	B	1	5.0E+00	2.00E+03	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBDATE
MO99 SMALL	.800	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	56.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.142	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.80E+04	3.80E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	6.37E+03	3.33E+04	3.33E+04	2.38E+04	0.	0.	2.38E+04	0.	0.
IR192 SOURC	5.60E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO_2	0.	0.	0.	0.	3.20E+02	0.	3.72E+02	0.	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.76E+04	1.64E+04	1.64E+04	1.64E+04	0.	0.	1.64E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH.SMALL	4.47E+03	2.33E+04	2.33E+04	1.67E+04	0.	0.	1.67E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	800	50	1000	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO_2	0	0	0	0	1200	0	50	0	0
MO99 LARGE	250	0	0	1000	0	0	0	0	0
MO99 SMALL	800	50	1000	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH.SMALL	800	50	1000	1000	0	0	200	0	0

B.1-5.2 Non-Radiological Impact

The non-radiological impacts resulting from this alternative, aside from the need for special security arrangements, are expected to be minimal because plutonium shipments are a very small fraction of the total radioactive material shipping picture.

Table VI -15. Summary of Results for All PuO_2 by Truck

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.167	0
Normal Transport (annual person-rem)	9589	9595	0
Accidents L.C.F.	5.59×10^{-4}	4.40×10^{-4}	21% decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	6.20×10^{-8}	16% decrease

Table VI -16. Summary of Results for All PuO_2 by Rail

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.165	0
Normal Transport (annual person-rem)	9589	9584	0
Accidents L.C.F.	5.59×10^{-4}	1.89×10^{-4}	factor of 3 decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	3.65×10^{-8}	factor of 2 decrease

The transfer of all air-shipped plutonium to either truck or rail results in essentially no change in total annual L.C.F. The savings in transporting by truck the 112 shipments that normally would go by air was estimated in Table VI -6 to be $3400 per year. However, the additional expense required for safeguarding those plutonium shipments in excess of 2 kg would probably exceed the savings in freight charges because guards would have to be employed for surface shipments. Since the safeguards requirements are currently under consideration by NRC, no estimate can be made at this time of the total cost.

B.1-6 All Spent Fuel By Truck

There is currently little spent fuel being shipped because of the lack of operational fuel reprocessing plants for LWR fuels. The massive nature of the spent fuel casks implies that the transport of spent fuel by truck instead of rail is likely to mean more shipments, each with fewer elements in smaller casks, in order to keep the total mass within the tonnage limit for the truck mode. Considering present-day fuel element casks which

allow seven fuel elements to be transported by rail in a single cask and s.. le element casks used for truck shipments, as much as a sevenfold increase in the number of shipments would be required under this alternative. It is assumed that each single-element truck cask has the same external radiation level as the seven-element rail cask. The standard shipments for this alternative are shown in Table VI -17.

B.1-6.1 Radiological Impacts

The radiological impacts from this alternative are summarized in Table VI -18. The changes in total radiological impact are small; an increase of approximately 177 person-rem or 2% in population dose results from normal transport operation. The increased exposure of people on and around the transportation link and the increased number of shipments account for the increase in population dose.

The mode shift produces a negligible change in accident risk, since the same total quantity of material is transported per year, even though it is in a larger number of shipments. The consequences of a single accident are reduced, because each vehicle carries a smaller quantity of material.

Table VI -18. Summary of Results for All Spent Fuel by Truck

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.188	+2%
Normal Transport (annual person-rem)	9589	9766	+2%
Accidents L.C.F.	5.59×10^{-4}	5.59×10^{-4}	0
Probability of $\geq$ 1 Fatality per Year	7.40×10^{-8}	7.4×10^{-8}	0

TABLE VI -17. All Spent Fuel by Truck

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO_2	.3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBNATE
MO99 SMALL	.600	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	56.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	0.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID
RAPH.SMALL	.042	A	3	5.0E-01	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.80E+04	3.80E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	6.37E+03	3.33E+04	3.33E+04	2.38E+04	0.	0.	2.38E+04	0.	0.
IR192 SOURC	6.80E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO_2	2.60E+02	0.	0.	1.12E+02	0.	0.	1.12E+02	0.	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.70E+04	1.64E+04	1.64E+04	1.64E+04	0.	0.	1.64E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	3.80E+02	0.	0.	0.	0.	0.	0.	0.	0.
SFI	3.80E+02	0.	0.	0.	0.	0.	0.	0.	0.
SFFP	3.80E+02	0.	0.	0.	0.	0.	0.	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH.SMALL	4.47E+03	2.33E+04	2.33E+04	1.67E+04	0.	0.	1.67E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	500	50	1000	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO_2	1200	0	0	1200	0	0	50	0	0
MO99 LARGE	250	0	0	1000	0	0	0	0	0
MO99 SMALL	600	50	1000	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	0	0	0	0	0
SFI	1000	0	0	0	0	0	0	0	0
SFFP	1000	0	0	0	0	0	0	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH.SMALL	600	50	1000	1000	0	0	200	0	0

B.1-6.2 Non-Radiological Impacts

The non-radiological impacts arising from this option are likely to be largely economic. The estimated costs for shipment of irradiated fuel by rail and by truck are shown in Table VI -19. It is evident from the table that the cost for transporting seven single-element casks by truck is about the same as for transporting one seven-element cask by train.

Table VI -19. Economics of Rail-Truck Mode Shift for Spent Fuel

	Regular Freight Train*	Truck**
7 element shipment	$9000	$9000

*100 Ton, 7 element fuel casks
**8 Ton, 1 element fuel casks

Since there is no significant cost difference involved, and there is in fact a slight increase in annual L.C.F., the alternative of transporting all spent fuel by truck does not appear to be cost effective.

B.1-7 All SSNM by Cargo Air and Helicopter

This alternative was chosen to evaluate the risk resulting from adoption of proposals suggesting* that transport by air represents a more secure secondary transport mode for SSNM. The calculation of the radiological impact only addresses a mode change for plutonium (see Table VI -20), since plutonium is the principal hazardous member of the SSNM group. Thus, all plutonium shipments are considered to be transported by cargo aircraft, with helicopter serving as the secondary mode for transporting the material to and from the airports.

*See discussions of Security and Safeguards, Chapter VII.

TABLE VI -20. All SNM by Cargo Air and Helicopter

MATERIAL	CI/PKG	PKG TYPE	PKG/SHP	TI/PKG	REM/CI	MATERIAL DESCRIPTION
TC-99M	.280	A	3	1.0E-01	8.90E+01	SOLUBLE LIQUID
I131 SMALL	.012	A	3	8.0E-01	1.10E+06	SOLUBLE SALT
IR192 SOURC	100.000	SF	1	2.0E+00	0.	INSOLUBLE METAL
IR192 R.M.	5000.000	B	1	4.0E+00	1.00E+05	INSOLUBLE METAL
PuO2	3628	B	1	5.0E+00	2.00E+08	INSOLUBLE OXIDE
MO99 LARGE	80.000	B	1	3.6E+00	2.10E+04	INS MOLYBNATE
MO99 SMALL	.600	A	2	2.4E+00	2.10E+04	SOLUBLE OXIDE
I131 LARGE	58.700	B	1	1.6E+00	1.10E+06	SOLUBLE LIQUID
SFKR	2000.000	CASK	1	0.	6.10E-01	GAS
SFI	2.000	CASK	1	0.	1.10E+06	SOLUBLE SALT
SFFP	800.000	CASK	1	1.0E+02	4.00E+04	SOLUBLE OXIDE
RAPH.LARGE	74.000	B	1	1.7E+00	1.10E+06	SOLUBLE LIQUID

SHIPMENTS PER YEAR

MATERIAL	TRUCK	P. VAN	PASS. AIR	CARGO AIR	RAIL	SHIP	C. VAN	HELICOPTER	AIR TAXI
TC-99M	0.	3.80E+04	3.80E+04	0.	0.	0.	0.	0.	0.
I131 SMALL	6.37E+03	3.33E+04	3.33E+04	2.38E+04	0.	0.	2.38E+04	0.	0.
IR192 SOURC	6.60E+03	0.	0.	0.	0.	0.	0.	0.	0.
IR192 R.M.	0.	0.	0.	1.30E+02	0.	0.	1.30E+02	0.	0.
PuO2	0.	0.	0.	3.72E+02	0.	0.	0.	3.72E+02	0.
MO99 LARGE	7.20E+03	0.	0.	7.20E+03	0.	0.	0.	0.	0.
MO99 SMALL	1.78E+04	1.64E+04	1.64E+04	1.64E+04	0.	0.	1.64E+04	0.	0.
I131 LARGE	0.	0.	0.	1.00E+03	0.	0.	1.00E+03	0.	0.
SFKR	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFI	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
SFFP	5.40E+01	0.	0.	0.	3.26E+02	0.	3.26E+02	0.	0.
RAPH.LARGE	0.	0.	0.	2.70E+03	0.	0.	2.70E+03	0.	0.
RAPH.SMALL	4.47E+03	2.33E+04	2.33E+04	1.67E+04	0.	0.	1.67E+04	0.	0.

MILES PER SHIPMENT

TC-99M	0	50	1000	0	0	0	0	0	0
I131 SMALL	600	50	1000	1000	0	0	200	0	0
IR192 SOURC	1000	0	0	0	0	0	0	0	0
IR192 R.M.	0	0	0	1000	0	0	50	0	0
PuO2	0	0	0	1200	0	0	0	50	0
MO99 LARGE	250	0	0	1000	0	0	0	0	0
MO99 SMALL	600	50	1000	1000	0	0	200	0	0
I131 LARGE	0	0	0	1000	0	0	50	0	0
SFKR	1000	0	0	0	1000	0	50	0	0
SFI	1000	0	0	0	1000	0	50	0	0
SFFP	1000	0	0	0	1000	0	50	0	0
RAPH.LARGE	0	0	0	1000	0	0	50	0	0
RAPH.SMALL	600	50	1000	1000	0	0	200	0	0

B.1-7.1 Radiological Impacts

The changes in radiological impacts which result from this mode shift are shown in Table VI -21. While the normal transportation population does is essentially unchanged, there is an increase in population risk from accidents resulting from this mode shift. A comparison of these results to those in Table VI -15 for all plutonium shipped by truck shows that the number of accident-produced latent cancer fatalities is a factor of 1.8 times that for the case of shipping all SSNM by truck. The probability of 1 or more early fatalities per year is 32% greater for the cargo air/helicopter case than for the truck only case.

B.1-7.2 Non-Radiological Impacts

The primary non-radiological impact of this alternative would result from the security costs of safeguarding the SSNM. Since the security costs are likely to outweigh the transportation costs differences between the baseline case and this alternative, and because the security requirements are currently under consideration at the NRC, no satisfactory estimate of the economic impact can be made at this time.

Table VI -21. Summary of Results for All SSNM by Cargo Air and Helicopter

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.163	0
Normal Transport (annual person-rem)	9589	9563	0
Accidents L.C.F.	5.59×10^{-4}	7.73×10^{-4}	38% increase
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	8.18×10^{-8}	11% increase

B.2 Operational Constraints on Transport

In this section the effects of placing safety restrictions on carriers of radioactive material are considered. Four general topics are addressed: (1) restricting the specific type of vehicle, (2) restricting air transport to lower risk flight conditions, (3) restricting highway transport to lower risk driving conditions, and (4) restricting rail transport of irradiated fuel to special trains. The results are compared with the baseline standard shipments.

B.2-1 Vehicle Model Restrictions

Studies have been conducted[5] which indicate that certain specific air transport vehicles have better safety records than others. This fact suggests that constraints might be applied to air carriers to limit the choice of aircraft used for radioactive materials shipments. In order for this alternative to be evaluated, several features must be considered:

a. Larger planes carry more passengers, more flight attendants, and may have larger flight crews but have lower TI-to-dose-rate conversion factors for passengers, attendants, and crew because of their larger size.
b. Smaller planes carry fewer passengers, flight attendants, and crew but have higher TI-dose-rate conversion factors because materials are stowed closer to the cabin and/or cockpit.
c. Restrictions on type of aircraft may create scheduling constraints if a particular type of aircraft does not service a particular airport, does not adhere to a useful schedule, or is not used by a particular carrier.

The baseline analysis was performed using "average" values for accident rates from the National Transportation Safety Board (NTSB)[6]* and average values for TI-to-dose-rate conversion factors.[7] In order to consider the effects of specific aircraft for both passenger and cargo service, the accident rate specified for the aircraft model[5] under consideration is used. The effects of differences in numbers of passengers, crew, and flight attendants are handled in a similar way. The TI-dose-rate conversion factors are estimated to be inversely proportional to the squares of the lengths of the various aircraft models.[8] The results are summarized in Table VI -22. Based on this table, the choice of aircraft can produce up to a 10 percent increase in the normal transport L.C.F. (a 50 percent occupancy figure was used).

Four aircraft models considered resulted in a decrease in total annual L.C.F. (see Table VI -22). The Convair-880 four engine turbojet gave the greatest reduction: 0.016 L.C.F. per year or equivalently, $130,000 per year. However, a comparison of the operating costs using 1974 CAB data reveals that the Convair 880 costs about $40 per hour more than the Boeing 727-100. The $130,000 per year benefit would be completely offset by the increased direct operating costs alone in 1100 flights, which is about two orders of magnitude less than the total number of flights per year carrying radioactive material.

The greatest contribution to the annual L.C.F. resulting from accidents involving radioactive materials shipments is

*These values are conservative since they include all air carriers. Turbofan and turbojet values are generally lower (as reflected in the following table) and these aircraft are usually used for commercial RAM flights.

TABLE VI -22

Summary of Results from Use of Various Models of Aircraft

	Base Line 60 Passengers* 4 Attendants 133 Ft. Long (Boeing 727)	4-Engine Turbofan 90 Passengers* 6 Attendants .84 TI/dose factor** (Boeing 707)	2-Engine Turbofan 60 Passengers* 4 Attendants 2.0 TI/dose factor** (Boeing 737)	3-Engine Turbofan 95 Passengers* 6 Attendants .76 TI/dose factor** (Boeing 727-200)	4-Engine Turbojet 55 Passengers* 4 Attendants .94 TI/dose factor** (Convair 880)	4-Engine Turboprop 50 Passengers* 4 Attendants 1.7 TI/dose factor** (Lockheed L-188)
LCF Accident	5.59×10^{-4}	3.9×10^{-4}	4.86×10^{-4}	4.27×10^{-4}	4.44×10^{-4}	7.58×10^{-4}
Person-rem/year (normal)	9589	9827	10,510	9772	9465	9939
LCF Normal	1.166	1.195	1.278	1.188	1.151	1.215
Total LCF	1.167	1.195	1.279	1.188	1.151	1.216
Probability of Short Term Fatality per year	7.40×10^{-8}	5.59×10^{-8}	6.65×10^{-8}	6.00×10^{-8}	6.19×10^{-8}	9.64×10^{-8}

*a 50% occupancy figure is assumed in obtaining this value.

**This factor, when multiplied by the TI/doserate conversion factor for the baseline case, gives the TI/dose-rate conversion factor for this alternative.

made by plutonium. Approximately the same reduction in accident-caused by L.C.F. (with no increase in normal case L.C.F.) could be achieved by requiring only plutonium shipments to be transported by aircraft models with lower accident rates. Since comparatively few shipments would be involved in this case, the alternative would probably be cost-effective. This feature is common to the following alternatives which result in reduced accident ratio.

B.2-2 Air Transport Restrictions

B.2-2.1 Prohibit Shipments of Radioactive Materials under Adverse Weather Conditions

Statistics[5,6] show that a major factor in 32 percent of air carrier accidents is adverse weather conditions. Since most instrument flight rules (IFR) accidents are landing accidents;[5,9] an appropriate restriction might be expressed as a necessity for visual flight rules (VFR) conditions at the destination airport. If all radioactive material flights were required to follow this restriction, the accident rate would be reduced to 78 percent of the baseline value. As noted in Table VI -23, a 10 percent reduction in annual expected latent cancer fatalities results from accidents involving RAM shipments. This change does not affect the normal mode impact. Some potential implications of this alternative are:

TABLE VII-23 Summary of Results for Limiting Operation Under Adverse Weather Conditions

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.166	0
Normal Transport (annual person-rem)	9589	9589	0
Accidents L.C.F.	5.59×10^{-4}	5.05×10^{-4}	10% decrease
Probability of $\geq$ 1 Early Fatality per Year	7.40×10^{-8}	6.86×10^{-8}	7% decrease

a. Short half-life materials might have to be shipped from supplier to user in substantially larger quantities to insure that weather-caused delays would not result in excessive radioactive decay of the material before it reaches the user. A severe storm might necessitate IFR restrictions from a few hours to 3 or 4 days. If a Tc-99m supplier were forced to allow for a 72-hour delay, he would have to increase the number of curies shipped by a factor of about 4100. In the case of Mo-99, the amount would have to be doubled; and, in the case of I-131, the quantity would have to be increased by a factor of about 1.3. Some effects would be higher TI values, more shielding required, and larger raw material requirements.

b. Use of scheduled carriers would be virtually impossible since they normally meet their schedules only by flying during both IFR and VFR conditions. This might force a switch to an exclusive charter air taxi service with its attendant higher accident rates and potentially higher crew exposures (if smaller aircraft were used). Another possibility is that the shippers might be forced to contract for the exclusive use of commercial aircraft to ship their material or to take special routes to avoid IFR situations. Finally, cargo handling and management schemes would need to be improved to enable on-load, off-load, and shuttling of materials between flights during adverse orpotentially adverse weather conditions. This implies not only additional expense but also higher dose to handlers and warehouse personnel. The potential for several days of warehouse storage awaiting VFR conditions also implies additional dose to warehouse personnel.

c. Development of IFR conditions during flight or emergency needs for radioactive materials during IFR conditions would have to be analyzed, and provisions for exceptions would have to be included in the regulations.

The reduction in total annual L.C.F. is negligible, and the cost for implementing the alternative, as discussed, could be very large. One airline estimates that the cost of grounding of Boeing 727-200 aircraft for one day is about $20,000, or about $830 per hour. The total number of hours of flying by commercial aircraft under IFR conditions is far greater than that which would offset the relatively benefit which would result.

B.2-2.2 Permit Radioactive Materials to be Carried on Daytime Flights Only

Statistics[5,6] show that a major factor in 25 percent of air carrier accidents is nighttime flight. As shown in Table VII-24, restricting flights to daylight hours reduces the accident latent cancer fatalities and the annual early fatality probability about 10 percent below baseline values. As in B.2-2.1, the normal case results are not changed. This alternative permits regular scheduling and does not require substantially larger amounts to be shipped from supplier to user although a slight increase might be required for a transcontinental shipment of very short half-life material.

TABLE VI -24 Summary of Results for Only Daytime Flights

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.166	0
Normal Transport (annual person-rem)	9589	9589	0
Accidents L.C.F.	5.59×10^{-4}	4.98×10^{-4}	11% decrease
Probability of $\geq$ 1 Early Fatality per Year	7.40×10^{-8}	6.79×10^{-8}	8% decrease

The total number of annual L.C.F. is reduced by a negligible amount; however, the slight reduction in accident L.C.F. could be achieved at very little additional cost.

B.2-2.3 Restrict Flights Carrying Radioactive Materials such that High Population Zones are Avoided

In this alternative the use of airports in suburban population zones rather than major metropolitan airports is considered. An example of such a change would be use of Ontario Airport in Ontario, California, in place of Los Angeles International Airport. This alternative is modeled by changing the fraction of travel in high and medium population zones for aircraft and associated van links. The fact that flights avoid high population density zones means a substantially lower population risk resulting from flight accidents since the bulk of airplane accidents occur in the immediate vicinity of airports during takeoff or landing.[9]

If air shipments through high population zones are eliminated, the consequence of the maximum accident scenario (a class VIII accident dispersing plutonium-239) is reduced by a factor of 10, which corresponds to the reduction in the population density at the potential accident site.

Some additional considerations relating to this alternative are:

a. The choice of available carriers could be restricted, since not all major carriers, particularly cargo air carriers, provide comprehensive service to suburban airports.

b. Additional secondary mode (van) mileage necessitated by the longer distance from primary link terminus to final user implies an additional annual cost of about $1.5 million (at a cost of 13¢/mile). If the longer secondary mode trip uses freeways wherever possible at an average speed of 45 miles per hour, the additional cost for salaries would be $21 million (at a rate of $6 per hour for an operator).

c. It should be noted that some major urban airports are already located in lower density population zones (e.g. Dulles International Airport).

TABLE VI -25 Summary of Results for Flights Avoiding High Population Zones

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.097	6% decrease
Normal Transport (annual person-rem)	9589	9021	6% decrease
Accidents L.C.F.	5.59×10^{-4}	6.13×10^{-4}	10% increase
Probability of $\geq$ 1 Early Fatality per Year	7.40×10^{-8}	8.62×10^{-8}	16% increase

The total annual L.C.F. is reduced by 0.069 L.C.F., equivalent to $567,000 per year. When compared to the annual additional cost of 22.5×10^6 associated with the longer secondary mode trip, it is clear that the cost of the alternative is much greater than the monetary value of the decreased dose.

B.2-3 Highway Transport Restrictions

B.2-3.1 Route Trucks on Turnpikes or Interstate Highways, Restrict Driving to Periods of Good Weather, or Specify Additional Training for Truck and Van Drivers

The net result of any of these three alternatives reduces the truck accident rate by about 10 percent.[10] This reduction in truck accident rate has a relatively small effect on the overall impact of radioactive material transportation. See Table VI-26 for the actual results achieved.

Restricting trucks to good weather driving has the same attendant problems as that for the VFR-only rule considered earlier. A potential problem is the possibility that a truck could be forced to stop for several days in a high population density area to wait for weather to clear. The resulting additional population exposure might be significant. As with the aircraft IFR restriction, additional warehouse storage and multiple handlings would increase the population dose.

Specific training for truck and van drivers to avoid stops in high population areas, to minimize stop times, to pick routes to avoid population centers, and to correctly handle and stow packages would minimize the impact of the van portion of the air transport mode. Because of the large number of variables involved, no effort was made to quantify this effect. It is sufficient to note that of the 7005 person-rem charged to modes involving a secondary link (cargo air, passenger air, and rail) 5229 person-rem results from the secondary link.

Turnpike routing is generally used by most long-haul carriers since limited-access highways provide the most direct routes and optimal driving conditions. Since the truck must still

pick up merchandise, make deliveries, and refuel in populated areas, the normal dose would not be substantially reduced.

Table VI -26. Summary of Results for Decreasing Truck Accident Rates

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.166	0
Normal Transport (annual person-rem)	9589	9589	0
Accidents L.C.F.	5.59×10^{-4}	5.28×10^{-4}	6% decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	6.98×10^{-8}	6% decrease

B.2-3.2 Restrict Trucks Carrying Radioactive Materials to a Maximum Speed of 45 mph

Restricting trucks to a lower speed limit (for instance, 10 mph below posted limits) reduces the highway accident rates by about 5 percent.(10) This has a small effect on the accident impact; however, trips take longer, and the exposure to people living along the highway and to people sharing the highway with such trucks increases slightly. A non-radiological effect of this alternative would be an additional annual travel time of 8.4×10^4 hours (using 45 mph highway speed and shipment data assumed in the model), corresponding to $1 - 2 million in additional salaries and vehicle and equipment use costs. The costs might be partially offset by a small decrease in operating expenses resulting from improved fuel consumption and reduced maintenance. Since all trucks would not be affected, law enforcement officials would be hampered in their ability to enforce the reduced speed limit. The change in radiological consequences for this alternative are shown in Table VI-27.

Table VI -27. Summary of Results Restricting Truck Speed to 45 mph

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.170	0
Normal Transport (annual person-rem)	9589	9620	0
Accidents L.C.F.	5.59×10^{-4}	5.43×10^{-4}	2% decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	7.18×10^{-8}	3% decrease

This alternative is clearly not cost effective since it results in a slight increase in total annual L.C.F. and in a higher cost.

B.2-3.3 Restrict Trucks from Traveling on Weekends

Prohibiting inter-city truck travel on weekends provides a significant reduction (50%) in truck accident rates.[5] The change in accident LCF and annual early fatality probability are approximately 30%. In the analysis of this alternative, it was assumed that secondary mode transport was not restricte to weekdays only in order to serve the aircraft shipping modes.

Prohibition of weekend truck travel might prove a burden to radiopharmaceutical shippers and users since a large number of short half-life isotopes are shipping on Saturday evening to arrive for use on Monday morning. One result might be shipment on Friday for use on Monday with an associated increase in required amount of material shipped from supplier to user to allow for weekend decay. This would increase the package TI value or require more shielding. Another possibility would be a restructuring of radiopharmaceutical use by physicians to allow for later deliveries. Results of adopting this alternative are shown in Table VI-28.

Table VI -28. Summary of Results for No Weekend Transport

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.166	0
Normal Transport (annual person-rem)	9589	9589	0
Accidents L.C.F.	5.59×10^{-4}	4.08×10^{-4}	27% decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	5.24×10^{-8}	29% decrease

The benefit, i.e., the reduction in annual L.C.F., in this case is only $1200 per year. The cost for the additional material alone would exceed this figure. Thus, it does not appear to be cost effective.

B.2-4 The Use of Special Trains for Irradiated Fuel Shipments

The effects of an action requiring the use of special trains for irradiated fuel shipments are considered in this section. A special train used exclusively for spent fuel shipments could presumably travel at a slower speed than ordinary freight trains carrying both spent fuel and other cargo. The severity of a possible train accident involving the special train should, on the average, be less as a result of the reduced speed, with a correspondingly reduced probability of release of the contents.

In their study and classification of freight train accidents Clarke et al.[12] noted that approximately 83% were derailment accidents, 7% were collision accidents, and about 10% were attributed to other causes. Grade crossing accidents were not considered, since they rarely involve significant damage to the cargo. Almost 90% of all derailment accidents occurred at speeds less than 40 mph. Thus, it is difficult to see how the use of special trains at reduced speeds (35-40 mph) could substantially

reduce derailment accidents. Collision accidents probably wouldn't be reduced as long as the special train shared the track with other trains.

If it were possible for special use trains to avoid populated areas, the population exposure resulting from normal transport would be only slightly reduced, since spent fuel shipments contribute only about 6% to the normal transport population exposure. Since most railroads pass through urban areas rather than around them, the special trains would be forced to go through urban areas unless special tracks were laid to avoid them. Furthermore, the reduced speeds would probably result in greater exposure to the surrounding population, which accounts for 86% of the baseline normal transport population dose from spent fuel shipments by rail.

The cost of a spent fuel shipment involving seven fuel elements by dedicated train is estimated to be $24,000, vs $9,000 by regular freight train or truck (see Table VI -19). If all 380 annual spent fuel shipments considered in the baseline case were transported by special train, the additional cost would be $\$5.7 \times 10^6$ per year. In order to justify this cost from a risk point of view, the total annual L.C.F. would have to be reduced by about 0.7 L.C.F., or roughly by about a factor of 2. Since spent fuel shipments account for .065 L.C.F. per year, including the contributions of both normal transport and accidents, the use of dedicated trains does not appear to be cost-effective.

B.3 Restriction on Form or Quantity Shipped

The physical and chemical form of radionuclides transported can strongly influence the amount of material released in an accident and the pathway to eventual radiation exposure of man. Restricting the maximum quantities of radioactivity allowed on

a vehicle limits the amount of material available for release in an accident, and hence the magnitude of the consequences.

B.3-1 Restrict the Physical and/or Chemical Form of Shipped Material

In Chapter V, serious radiological consequences were noted when plutonium bearing particles were deposited in the lungs. This deposition occurs for such particles having aerodynamic diameters smaller than 10 micrometers; larger diameter particles have a very small probability of pulmonary depositin and consequently do not constitute as severe a health hazard to man. Thus, the consequences of an accident are directly proportional to the respirable fraction of the material released.

A fabrication technique for production of fuel containing plutonium to be used in reactors involves precipitation of the oxalate and calcination to produce PuO_2 powder. One fuel fabricator believes that, ny relatively small changes in process parameters, the respirable fraction of the PuO_2 powder might be significantly reduced if such a modified process were developed. Another possible method of reducing the quantity of respirable material released in an accident is pelletizing the PuO_2 powder prior to shipment. It might be possible by either technique to reduce the respirable fraction of particles released in an accident to 1 percent of the total quantity shipped.

The results of achieving such a respirable fraction is shown in Table VI -29. Although no change in normal transport annual L.C.F. results, a factor of 16 decrease is obtained in accident L.C.F. In addition, because of the reduction in respirable fraction, doses received by individuals in close proximity to a release would be sufficiently low that the probability of early fatality (by pulmonary fibrosis) is negligible compared with the baseline case.

Table VI -29. Summary of Results of Limiting PuO_2 Respirable Fraction

	Baseline (20% resp. Pu)	Alternative (1% resp. Pu)	Change
Normal Transport L.C.F.	1.166	1.166	0
Normal Transport (annual person-rem)	9589	9539	0
Accidents L.C.F.	5.59×10^{-4}	3.54×10^{-5}	factor of 16 decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	0	100% decrease

The reduction in L.C.F. corresponds to an annual benefit of $4300. Although a process for reducing the respirability of PuO_2 has not yet been developed, the process development cost may be sufficiently small to make this alternative cost-effective.

B.3-2 Restrict Material Shipped per Vehicle

Under the assumption that a given amount of material will have to be shipped, the reduction of the amount allowed on any given vehicle would simply result in more shipments. Increased transportation costs and, for SSNM shipments, increased security costs would result from this restriction without a corresponding reduction in the annual population dose or in the risk due to accidents. However, the consequence of an accident, should one occur, is reduced in proportion to the reduction of the amount of material on a given vehicle.

B.4 Revision of Packaging Standards, Package Quantity Limits and TI Limits

The alternatives considered in this section are concerned with the reduction in the risk of transporting radioactive

materials by three general methods. The first is a revision of the packaging standards to assure survivability (no release of radioactivity) in all but the most extreme accident conditions. The second involves a lowering of the quantity limits for radioactive materials packages, thus limiting the amount of radioactive material available for release in any given accident. Finally, the effects of lowering the package TI limits are discussed.

B.4-1 Revision of the Packaging Standards

The results of the risk analysis for current shipping practice have shown that the expected contribution of accidents involving radioactive materials shipments to the overall annual population dose is negligible compared to the normal transport contribution. Even though the probability of occurrence of a severe accident involving plutonium, for example, is very small, the consequence of such an accident could be large. It is for this reason that alternatives which reduce the amount of radioactive material dispersed in an accident are considered.

Since current packagings (Model II release fractions) are considerably better than the regulatory standards require (Model I), as shown in Table V-2, new packaging standards could be introduced which would, in effect, require that all new packaging designs be at least as good as those currently in use. Such an action would not result in a decrease in risk due to accidents but would insure that the risk would not increase as a result of the introduction of new packagings inferior to present ones.

To see the effect of packaging standards revisions a third release fraction model (Model III) is considered. It differs

from Model II (a conservative approximation to current container capabilities) in that no release of material is permitted for Type B containers for accident Categories I-VII, and only 5 percent release is allowed for Category VIII. No change is assumed in the Type A container release fractions. The results of the calculation are presented in Table VI -30. As in the previously considered alternative, the probability of early fatality is negligible compared with the baseline case.

Table VI -30. Summary of Results - Revised Packaging Standards

	Baseline	Alternative	Change
Normal Transport L.C.F.	1.166	1.166	0
Normal Transport (a nual person-rem)	9589	9589	0
Accidents L.C.F.	5.59×10^{-4}	2.39×10^{-5}	factor of 23 decrease
Probability of $\geq$ 1 Early Fatality per year	7.40×10^{-8}	0	100% decrease

A 23% reduction in annual accident L.C.F. results from revised packaging standards which would insure release fractions no greater than those for Model III. Certain containers currently in use may be capable of meeting these standards, either as presently designed or with minor modifications. Since accidents involving plutonium shipments are expected to produce 98.6% of the total accident risk in the baseline case, the required use of such containers only for plutonium shipments would produce essentially the same decrease in annual accident L.C.F. The NRC is currently sponsoring container tests at Sandia Laboratories using existing containers at impact velocities well into category VIII. The test results indicate that certain existing containers, perhaps with minor modifications at some increase in cost, might be capable of meeting the new standards. A cost benefit estimate cannot be made at this time pending information on manufacturing costs of a container which can be demonstrated to consistently meet the revised standards.

B.4-2 Lowering of Package Quantity Limits

A second possible method for risk reduction considered in this section is a lowering of the package quantity limits. Such action would reduce the amount of radioactive material per package available for release, and, if the same amount of shielding were used, the TI per package would be reduced also. However, unless a package TI reduction were required along with the quantity reduction, it would probably be more cost-effective to reduce the amount of shielding so as to lighten and reduce the cost of transporting an individual package. Consequently, the same total amount of material would continue to be transported, but in a larger number of packages. Thus, the net effect upon the annual accident risk would be unchanged.

With the TI per package remaining the same but a greater number of packages transported, the number of TI transported annually would be increased, and the routine exposure due to normal transport would be increased accordingly. Since normal transport accounts for essentially all of the risk for current shipments, the total risk would be substantially increased as a result of this response to lowering package quantity limits.

If the action lowering the quantity limits were accompanied by a corresponding requirement to reduce the package TI, the total TI transported annually would be unchanged. In this case there would be no change in either the accident or normal contribution to the risk, assuming, as before, that the total quantity of radioactive material transported annually remains the same. The net effect would be to transport the same quantity of radioactive material per shipment and per

vehicle, except in a larger number of packages. In either case shipping costs would be higher particularly in the second case where the action is accompanied by a required reduction in TI, because the total weight transported annually would be significantly higher. Higher costs with no change in annual L.C.F. indicates an unfavorable cost-benefit ratio.

B.4-3 Lowering the Package TI Limits

The final possible risk-reduction method considered in this section is a lowering of the package TI limits. Current standards allow up to 10 TI for packages with a Radioactive III - Yellow label. The reduction of the package TI can be accomplished in either or both the following ways:

a. a reduction of the quantity of material per package
b. an increase in the amount of shielding used per package

The first method was discussed in the preceding paragraphs and was shown to produce, at best, no change in the total annual risk. The second, i.e. an increase in the amount of shielding per package without reducing the quantity of material per package, could result in reduction in the number of TI shipped annually and in a corresponding reduction in the routine risk in normal transport. The effect of reduction in the maximum allowable package TI upon the annual risk of normal transport would depend upon the amount of the reduction and upon detailed information regarding current TI per package values. Information obtained by the authors from an informal survey of various industry representatives revealed no packages having a TI greater than 5 currently being shipped. The current effective radiopharmaceutical industry limit is 3 TI per package.[11] Radiopharmaceuticals comprise the majority of radioactive materials shipments, and as a result, make the greatest

contribution to the annual risk. A regulatory reduction in the TI package limits by a factor of two or three is estimated to have very little if any effect upon the overall risk, since it appears that package TI's have already been reduced by that amount.

A previous study[11] has compared the effects of package limits of 10, 5, and 1 TI with the effective present limit of 3 TI for transport of radiopharmaceuticals by passenger aircraft. The results showed that when the benefit/cost ratios are considered, the 5 TI limit is most cost-effective, and a TI limit of 3 exceeds the point of cost-effectiveness by a substantial margin. A TI limit of 1, however, was found to result in costs exceeding benefits by a factor of four.

Therefore, just as currently used packagings are much better than the standards require, the effective TI package limits are lower than required by the regulations. The TI limits could be lowered to the cost effective level of 5, for example, without affecting current shipping practice significantly and with no change in the overall risk. The result of such an action would be to insure that the present voluntary package limits are maintained. Unlike the introduction of new standards for packaging durability, a lowering of the TI limit from 10 to 5 would not require expensive container qualification tests. A reduction of the TI limit to less than 3, however, may not be cost-effective.

C. Summary of Radiological Effects of Alternatives

A summary of the radiological impacts of the various alternatives considered in this chapter is presented in Tables VI -31, VI -32, and VI -33 in terms of the reduction over the baseline case. In Table VI -31 the alternatives are ranked according to change in early fatality probability.

TABLE VI -31

Alternatives Ranked by Change
in Annual Early Fatality Probability

Alternative	Change
1% respirable plutonium Hardier packages	100% decrease
Ship all plutonium by rail	Factor of 2 reduction
No weekend truck travel	29% decrease
Use 4-engine turbofan (Boeing 707)	24% decrease
Shift all cargo air shipments to passenger air	23% decrease
Use 3-engine turbofan (Boeing 727-200)	18% decrease
Shift all air shipments to truck Ship all plutonium by truck Shift all cargo air shipments to truck Use 4-engine turboject (Convair 880)	16% decrease
Use 2-engine turbofan (Boeing 737)	10% decrease
No night flights	8% decrease
No IFR flights	7% decrease
Good weather driving Truck driver training Turnpike routing	6% decrease
Maximum truck speed limit	3% decrease
Shift all passenger air shipments to cargo air Ship all spent fuel by truck	No change
Ship all SSNM by cargo air/helicopter	11% increase
No flights in/over high population zones	16% increase
Use 4-engine turboprop (Lockheed L-188)	30% increase

TABLE VI -32

Alternatives Ranked by Reduction in LCF Accident

Hardier packages	Factor of 23 decrease
1% respirable packages	Factor of 16 decrease
Ship all plutonium by rail	Factor of 3 decrease
Use 4-engine turbofan (Boeing 707)	30% decrease
Shift all cargo air shipments to passenger air	28% decrease
No weekend truck travel	27% decrease
3-engine turbofan (Boeing 727-200)	24% decrease
Shift all cargo air shipments to truck	21% decrease
Ship all plutonium by truck	
Shift all air shipments to truck	
Use 4-engine turboject (Convair 880)	20% decrease
2-engine turbofan (Boeing 737)	13% decrease
No night flights	11% decrease
No IFR flights	10% decrease
Good weather driving	6% decrease
Truck driver training	
Turnpike routing	
Maximum truck speed limit	2% decrease
Ship all spent fuel by truck	No change
Shift all passenger air shipments to cargo air	
No flights in/over high population zones	10% increase
4-engine turboprop (Lockheed L-188)	36% increase
Ship all plutonium by cargo air helicopter	38% increase

TABLE VI -33

Alternatives Ranked by Reduction in LCF Normal

Shift cargo air shipments to passenger air	14% reduction
Use 4-engine turboject aircraft (Convair 880)	13% decrease
No flights in/over high population zones	6% decrease
Ship plutonium by cargo air and helicopter	No Change
No IFR flights	
Daylight flights only	
Good weather driving	
Truck driver training	
Turnpike routing	
No weekend truck travel	
Hardier packages	
1% respirable plutonium	
Truck speed limit reduction	
Ship plutonium by truck only	
Ship plutonium by rail only	
Shift cargo air shipments to truck	2% increase
Use 4-engine turbofan aircraft (Boeing 707)	
Use 3-engine turbofan aircraft (Boeing 727-200)	
Ship all spent fuel by truck	
Use 4-engine turboprop aircraft (Lockheed L-188)	4.2% increase
Use 2-engine turbofan aircraft (Boeing 737)	10% increase
Shift all passengers air shipments to cargo air	19% increase
Shift all air shipments to truck	33% increase

Table VI -32 ranks the alternatives in terms of the reduction in the average annual number of latent cancer fatalities resulting from accidents involving radioactive material shipments. The results for the first three alternatives are shown in terms of the reduction factor, while the remainder are expressed in terms of percent decrease or increase over the baseline case.

Finally, in Table VI -33 the alternatives are ranked according to their reduction in annual latent cancer fatalities resulting from normal transport. Many of the alternatives in this table produce an increase in the number of latent cancer fatalities.

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CHAPTER VII

SECURITY AND SAFEGUARDS

A. Introduction

The rapid growth of the nuclear power industry, coupled with an increase in terrorist activities, has increased concern over diversion or theft of nuclear materials, sabotage of nuclear facilities or other acts of terrorism. The possibilities of sabotage, radioactive contamination threats, and armed threats must be, and are being, weighed in the continuing process of threat assessment and establishment of appropriate countermeasures by the Nuclear Regulary Commission.

In general, these activities can be categorized by whether they occur through sabotage of nuclear facilities or theft and subsequent use of the nuclear material.

There are two groups of nuclear material that may require safeguarding: (1) certain strategic quantities and types of special nuclear material (SNM) such as high enriched uranium and plutonium and (2) a few radioisotopes such as cobalt-60.

All light water reactors at present use low enriched uranium in the fuel cycle. Low enriched uranium is not directly usable for nuclear explosives. On the other hand, highly enriched uranium (which is used in some test and research reactors and in high temperature gas-cooled reactors) and plutonium (which may be used in mixed-oxide fuel for light water reactors, and is produced in light water reactors) are useable for nuclear explosives. The few highly radioactive isotopes such as cobalt-60 could be used by a terrorist in the form of a dispersal weapon.

B. Safeguards Objectives and Programs

The objective of safeguards is to protect the public from harm or undue alarm arising from illegal, malevolent acts involving nuclear materials or facilities. To be effective, safeguards must be capable of preventing those acts that could ultimately result in a major civil disaster and must provide a high degree of protection against all other acts that could result in serious civil damage. To be acceptable, safeguards must not impose undue burdens on the public, in terms of civil liberties, environmental, institutional, and economic impacts. In furtherance of this objective, safeguards are designed to: prevent the unauthorized access to or acquisition of significant amounts of nuclear materials; provide protection against the sabotage of nuclear facilities; assure timely and adequate responses to the unauthorized acquisition of nuclear materials and to the sabotage of nuclear facilities; provide for timely and accurate information on the status of nuclear materials and facilities; and support effective international safeguards programs; while at the same time, minimizing adverse social impacts.

The program includes the following functional elements:

(1) Definition of the nature and dimensions of the threat.

(2) Development and imposition on the nuclear industry and contractors of safeguards requirements directed toward countering the threat.

(3) Licensing activities, including review of safeguards procedures proposed by nuclear industry and contractor applicants, as required by regulations.

(4) Inspection of safeguard implementation to ensure adequacy.

(5) Enforcement of requirements through administrative, civil, or criminal penalties.

(6) Administrative and technical support for response and recovery.

(7) Development and testing of methods, techniques, and equipment necessary to the effective implementation of safeguards.

(8) Frequent program review in the light of industrial/technical or social/political changes to assure that any needed changes are made in the program elements above.

Current programs are directed at protecting against theft or diversion of types and quantities of nuclear materials that could be used for nuclear explosives or contaminants and protecting against sabotage of nuclear facilities containing such materials. The present requirements are designed to protect against theft, diversion, or sabotage by one or two employees with access to the plant and material, by a small armed force attacking a plant or vehicle, or by both acting in combination. The approach to development of safeguards requirements is to provide "protection in depth," that is, to provide multiple opportunities to interrupt adversary action sequences.

Title 10 of the Code of Federal Regulations, Part 70, requires licenses in order to own, acquire, deliver, receive, possess, use, transport, import or export special nuclear materials. The NRC publishes specific safeguards requirements for materials and plant protection in 10 CFR Parts 70 and 73 and carries out the following activities to assure compliance:

(1) prelicensing evaluation of certain license applicant's proposed nuclear activities, including safeguards

procedures in the case of applicants for significant quantities of special nuclear material;

(2) issuance of a license to authorize certain activities subject to specific safeguards requirements; and

(3) inspection and enforcement to assure that applicable safeguards requirements are met by implementation of approved plans.

Safeguards requirements have been established for protecting special nuclear materials being moved between sites. Provisions in 10 CFR 73 include specific physical protection requirements that apply to licensees who ship five kilograms of U-235 (contained in uranium enriched to more than 20%), two kilograms of plutonium or U-233, or a weighted combination of these.

Regulation 10 CFR 73 prohibits licensee shipments aboard passenger aircraft of more than 20 grams or 20 curies, whichever is less, of plutonium or uranium 233 or 350 grams of uranium U-235 enriched to more than 20%.* When cargo aircraft are used, the number of enroute transfers are to be minimized and are to be observed by armed monitoring personnel.

During operation of a licensed plant and its related transportation links the NRC conducts inspections to assure continued effective implementation of material control requirements and protection plans. Each licensee is required to afford the NRC opportunity to inspect the nuclear materials; to perform or permit the NRC to perform necessary tests of materials and equipment; and to make available any records pertaining to possessions, use, or transfer of nuclear material.

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* There have been no air shipments of plutonium since the August 9, 1975 ban on such shipments by NRC. See Chapter I.

Inspection strategies are directed at achieving objectives on a systematic basis, where the scope, frequency, and intensity of inspection are determined primarily by considering:

(1) strategic value of the special nuclear material,

(2) the accessibility of the special nuclear material, and

(3) safety significance.

Secondary, but important, modifying factors are:

(1) prior inspection history of the facility and/or the shipments, and

(2) results of monitoring of facility records and reports, including inventory descrepancies, shipper-receiver differences, and normal operation losses/measured discards.

All transportation systems and their supporting safeguards security systems should be subjected to frequent inspections to insure continued effectiveness. The inspection system should, in addition to looking at compliance with existing regulations, continually evaluate the system based on current intelligence and operational considerations.

If items of noncompliance or deficiencies are found in the implementation of safeguards requirements by the licensee, the licensee is instructed to take prompt corrective action and to inform the NRC of the results. The NRC has the authority to modify, suspend, or revoke licenses and to impose civil penalties on licensees for noncompliance with the items and conditions of the license.

Procedures exist within NRC for response to:

(1) any suspected or actual theft of SNM or other material which could present a radiological hazard;

(2) any threat of sabotage to a facility containing such materials; and

(3) any threat involving the d[illegible]ctive use of such materials.

Response requirements for licensees toward threats are given in 10 CFR 73.50. Immediate measures must be taken to neutralize the threat, either by appropriate action by guards or call for assistance from local law enforcement authorities, or both. Licensee guards are expected at all times to (1) interpose themselves between SSNM and any adversary attempting entry and (2) intercept anyone exiting with such material. A sufficient degree of force should be applied to counter that degree of force directed at them, including the use of deadly force when the guard has a reasonable belief it is necessary in self-defense or in the defense of others.

Licensees are required to inform NRC promptly, and will normally inform local law enforcement agencies, in the event of a suspected or actual theft or sabotage.

Upon being informed of any of the foregoing circumstances, NRC would promptly inform the FBI, which has statutory responsibility for investigating such incidents. In addition NRC and ERDA would support the FBI with specialized assistance, especially in connection with the recovery of stolen material and would undertake to determine whether there is a potential hazard of nuclear explosive or radiological danger.

C. Relative Importance of Air Transportation and Safeguards

Chapter 1 reviewed the current industrial and medical uses of radioactive materials. It was noted that most of the applications take place at a site well removed from the point of production. The majority of packages of radioactive material (excluding fuel cycle requirements) shipped today contain radiopharmaceuticals. An estimated 600,000 packages of radioactive material were shipped in 1974 and were distributed as shown in Table I-3. Radiopharmaceuticals and medical research materials accounted for 95 percent of the total shipments with only 5 percent of the shipments used to transport research and industrial material.

Some shipments, as a result of their size and the isotopes involved, require more protection than others. Ideally each radioactive material shipment should be examined in terms of its potential for illicit use and the impact of such use. The category with potentially the greatest environmental impact includes shipments of strategic special nuclear materials (SSNM).*

Many types of radioactive materials would not be suitable for theft-dispersal purposes. Spent fuel, for example, is highly radioactive and is carried in massive casks, especially when shipped by rail. Therefore it would be relatively difficult for a group to carry it away with the intention of dispersing it elsewhere. Other materials, such as Cobalt-60, which are in special form, might be stolen and then dispersed in a highly populated area. Plutonium on the other hand can be used for both explosive purposes as well as a dispersal weapon since it is a very toxic substance.

*See Chapter II, Section J.

In addition, the successful sabotage of a plutonium shipment could also have serious consequences.

D. Transportation Security Systems

Security system success can be characterized by the sum of three probabilities: the probability of deterring an attempt at theft; the probability of maintaining control of the material if deterence fails; and the probability of recovering the material before it can be put to malevolent use if deterrence fails and control of the material is lost.

The capability to deter an attack, although difficult to analyze, is extremely important to the safeguards system. Even an unsuccessful attack could have extensive implications. Deterrence is primarily psychological; it results from the perception of a potential attacker that the risk in an attack exceeds the value of the target. Factors that may contribute to deterrence include publicity about some parts of the safeguards system, visibility and apparent invulnerability, alternative means of achieving his goal, and the past failures of attacks on the system. These factors do not lend themselves to quantification.

The protection system is broken into two classes: (1) those that emphasize personnel, such as escort guards and response forces; and (2) those that are technological in nature, such as barriers, alarms, communications, and the transportation model itself. Effective safeguards security systems use elements of both protection classes. The transportation modes that can be used to safeguard SSNM range from aircraft to conventional ground transport, to the use of modes such as rail and barge.

The recovery element of the security system includes use denial and search procedures followed by physical recovery. Recovery cannot be relied upon as the strong link in the security system. Relocation and recovery measures provide a fundamental and prudent element in a balanced, redundant safeguard system. They back-up the primary safeguard elements employed to deter or defeat any attempt to divert SNM or other radioactive material. Relocation capability is necessary because complete assurance of material control under all circumstances cannot be made. This also adds to the aura of deterrence. Hardware and techniques are currently available to allow a coordinated, effective relocation and recovery effort.

E. Transportation Modes

This section describes the safeguard aspects of the various modes used to transport SSNM and other sensitive radioactive material.* Some of the safeguards security systems being evaluated by NRC include the use of fixed wing aircraft (such as the C-130), helicopter, armored truck, integrated container road vehicle, safe secure trailer, rail, and barge transportation.

E.1 Air-Truck Mixed Mode

An air-truck mixed mode may offer advantages over ground transportation alone depending upon the length of the trip. Most short trips (200 - 500 miles) will still be made by truck alone, but for longer distances air transport,

* An indepth analysis is currently being undertaken by the Special Safeguards Study Group within NRC on the entire issue of Safeguards (including transport safeguards). The results of this study will be included in the forthcoming "Generic Environmental Statement Mixed Oxide Fuel (GESMO)".

combined with ground transport to and from the airfield, will lessen the exposure to accidental and planned incidents. The danger to road shipments increases as the distance to be traveled increases. Night stops, fatigue, repairs, and more difficult communication all contribute to an increased probability of problems.

Air shipments minimize exposure to threats and, with adequate precautions taken at transfer points, provide one of the most secure means of transporting SNM and other sensitive radioactive material for long distances. Given the development of an "air safe" container, shipments of SSNM by air-truck for longer distances may provide important advantages over ground transport alone.

Since trucks are necessary to complement an air transport system, the impact of air transport cannot be addressed without some mention of truck systems. The SSNM shipments would be protected by a varying number of escort vehicles and guards. The accompanying guards would provide the primary response to an emergency, and the number of guards would be varied to suit the particular shipment and preceived threat. A secondary response would be supplied by local law enforcement agencies (LLEA) located along the shipment route between facility and airport.

Prior arrangement for deployment of this LLEA assistance would be made depending, again, upon the geographic area, size of the primary guard force, type of material, and distance to be traveled. The combination of special vehicles, accompanying guard force, and secondary LLEA responses affords a flexible and effective deterrent and protection capability to the surface portion of the shipments.

The point of transfer of SSNM from truck to airplane in mixed-mode transportation, often considered the most vulnerable and sensitive segment of the air-truck transportation cycle, may be as secure as any other link in the transportation system. Transfer should be made at a location removed from the terminal buildings. The airplane security personnel would be present in addition to the security people accompanying the truck part of the shipment. The airport security personnel (police) would be available as a secondary response force in the event of an emergency. The transfer could well be the most secure portion of the shipment.

Air-truck transportation, as opposed to a purely air mode, could be the preferred means for transit for long distance shipments for the foreseeable future because of the generally impractical aspect of building airfields at the fuel cycle and reactor sites.

It may, under certain circumstances, be possible to use helicopters for transport from airfield to facility but the main secondary-transport method will remain road vehicle. The road distances to be traveled would be minimized, however, and the convoy will have the additional protection of the facilities's security force either to augment the existing convoy security force or to act as a response to emergencies during the trip between facility and airport.

Movement of sensitive radioisotopes, those that may be used for illicit purposes, would require less protection than that afforded SSNM. If later determined necessary, security personnel could be present at intermediate points. This would ensure that the material was not disturbed. Security personnel could be present at origin and destination. It should be noted

that these precautions may not be necessary. They serve to show only that adequate safeguard measures are available if it is determined that some isotopes need added protection.

Until the mid 1980's the shipping requirements for SSNM will be relatively small. Most of the SSNM shipments will be shipped by truck or a combination of air-truck depending upon the distance to be traveled. Most medical radioisotopes, needing less protection, if any protection, will continued to be moved by air.

E.2 The Use of Military Airfields

The feasibility of restricting flights to the use of military or joint military/civilian airfields as an added security measure has been examined. While it apears technically feasible to make use of military airfields and/or military aircraft to provide safeguards protection for the transportation of SSNM, there may be legal prohibitions which restrict or eliminate such use in the absence of congressional action. * Adequate protection can be afforded at civilian airfields.

E.3 All Air System

While it is discussed, an all-air system is not looked upon as being practical or feasible for the foreseeable future. An advanced all-air system

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* There are two statutes which make this practice of at least questionable legality. First, 31 U.S.C. 628 provides: "Except as otherwise provided by law, sums appropriated for the various branches of expenditure in the public service shall be applied solely to the objects for which they are respectively made." The second statutes ,18 U.S.C 1385, reads: "Whoever, except in cases and under circumstances expressly authorized by the Constitution or Act of Congress, willfully uses any part of the Army or the Air Force as a posse comitatus or otherwise to execute the laws shall be fined not more than $10,000 or imprisoned not more than two years, or both."

could provide "door-to-door" air transportation. A typical all-air transportation security system would deliver SSNM from the shipper to the receiver without intermediate transfer points thus minimizing exposure to theft or sabotage outside the fixed site facilities. A further advantage of air systems is the flexibility of routing to avoid population centers.

For short hauls, an alternative to trucks would be the use of helicopters or short take-off and landing (STOL) aircraft which do not require extensive runways as do conventional fixed-wing aircraft. Because of the limited range and payload capabilities, these aircraft might not be able to satisfy the entire shipping network. The use of STOL aircraft and helicopters would reduce points at which theft or sabotage could be attempted to only the loading and unloading transfer operations at origin and destination. Fixed-site guards would be available at these points to provide security while the aircraft are on the ground.

E.4 Road, Rail and Water Modes

Road is presently the preferred system for surface transport of SSNM. The primary advantages of this mode are accessibility to all nuclear facilities, flexibility of routing, direct service without the need to transfer cargo, and speed. Further coordination for response and the ability of response forces to arrive at the scene of an incident are more easily met.

The principal advantage of rail and water is that the time necessary for an adversary to gain access to the protected material might be increased because of the greater weight carrying capability and width of the carriers

which permits greater protective armor or other protective measures to be employed. The principal disadvantage of rail is the lack of variety in the positioning of guards with respect to the shipment; the whole guard force could be incapacitated by a single blow in a well-planned attack. A second negative point is that response forces access to the rail site might be seriously restricted. An attempt to increase the security of a rail or barge system by adding escort vehicles still does not achieve the level of security attained with escort trucks. The escorts can be readily identified; they have no lateral mobility to gain cover in case of attack; and they can be cut off more easily from the attack point.

A system of specially designed barges which combine cargo protection and jettisoning capabilities offers, at first glance, a possible advantage over truck transportation. Many facilities are not joined by navigable waterways; however, the advantages of site-to-site delivery would not be realized in a significant number of cases. Sinking of the SSNM containers could provide a very long delay time. However, this measure may not be appropriate if the barge is attacked while passing through a lock, under a bridge , or in a shallow draft channel. Finally, an act of sabotage in a major waterway could have extensive environmental effects. Here the transport media itself, water, could serve as the means of dispersing material from a remote region to one with high population density.

In summary, it appears that rail and barge are not as attractive as the road, air-truck, or all-air alternatives for the transport of nuclear material.

F. Conclusions

To maintain the environmental impact of the transportation of radioactive materials at its present low level, effective means must be continued to be provided to protect important quantities of radioactive material from theft and sabotage. Air transport provides the potential for one of a limited number of those effective means of protection. While further studies are being completed to determine the cost and effectiveness of alternative systems to protect radioactive material from theft and sabotage, the option of the air mode for such transportation should not be precluded.

APPENDIX A

ENVIRONMENTAL IMPACT LOGIC MODEL

I. Logic Model Development

The logic "roadmap" used to approach the complex problem of radioactive material transportation impact analysis was constructed using fault tree and event tree symbology. This approach was chosen because it is an effective method of identifying the elements and interactions that could lead to environmental impact.

The analysis involved a scenario and consequence development for all modes of transportation* which could be used to transport radioactive materials. An effort was made to consider all methods of employing a transport mode and of imperiling a shipment of radioactive material. This was done to allow consideration of all impacts, no matter how slight, and all scenarios, no matter how unlikely. This method was employed to seek completeness and to insure that an event of low probability but high potential consequence was not eliminated from consideration.

No effort was made to attach probabilities or quantified effect estimates to developed events in the "roadmap" model. Instead, the effort was devoted to making the model as complete as possible with the intention of using it as a guide for subsequent detailed analysis and quantification in areas warranting further attention, using a simplified edition of the model.

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*Mode: A major transportation system, i.e., air, highway, rail.

Operation: A subset of the mode, i.e., landing/takeoff, storage, refueling. These are operations incident to transportation in general.

Scheme: An overall national transportation plan using various modes in various amounts.

Foremost among the environmental impacts is the radiological impact from exposure to external penetration radiation or from accidental release of radioactive material. However, in the effort toward completeness, scenarios which lead to an "environmental impact" described by an economic effect, political effect, legal effect or public reaction effect, are also included, even though no radioactive release (in the conventional sense) may have occurred. An example of type of impact might be the situation where an item of radioactive material is lost in shipment. The impact in this case might be measured in terms of the dollar cost of a search instead of person-rem.

The model development centered around the takeoff/landing operation of the air transport mode. Because of the generality and broad scope of the development of the analysis of this operation, the operations of non-air modes and the remaining operations of the air mode were not developed as exhaustively.

II. Discussion of the Logic Model

The top event in the "roadmap" logic model* (shown in Figure A-1) is "Environmental Impact of Transportation of Radioactive Material." This event is purposely generalized to avoid restrictions which might be necessitated by precise definitions of "Environmental Impact," "Radioactive Materials," and "Transportation." Each of these terms is developed in subsequent tiers of the logic model. In Figure A-1, environmental impacts are considered for all potential modes of transport. The event of initial interest is EI1-1 -- the air mode. Initial subdivisions of event EI1-1 are shown in Figure A-2, where various types of air transport are considered.

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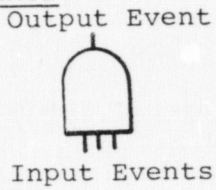
*Table A-1 gives a brief description of the sympology used in the logic model.

TABLE A-1

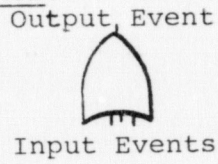
FAULT TREE SYMBOLS

AND GATE:



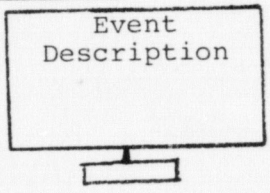
The AND gate describes the logical operation whereby the coexistence of all input events are required for the output to occur

OR GATE:



The OR gate describes the logical operation whereby the output event will occur if one or more of the input events occur. This allows combinations but does not explicitly allow for synergistic combination of events.

EVENT BLOCK:

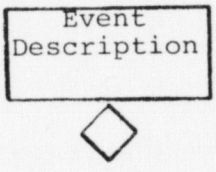


A rectangle above a gate identifies an event that occurs as a result of some combination of the occurrence of other events in the tree. The number in the small box below the rectangle is unique number assigned to the event as a "bookkeeping" aid.

BASIC EVENT:

The circle (or rectangle above a circle) identifies a basic event. A basic event is a fault-type event whose causes will not be further identified.

UNDEVELOPED EVENT:



The diamond identifies an event whose causes have not been identified because the event is of insufficient consequences; necessary information is unavailable, or because the event is beyond the scope of the study.

EXTERNAL EVENT:

The house identifies a basic event which is not further developed and which does not describe a fault-type event.

TRANSFER IN:

TRANSFER OUT:

The triangles are used as transfer symbols. The event logic flows from the transfer-out symbol to the transfer-in symbol in a manner as if the events or gates were connected directly with a single line.

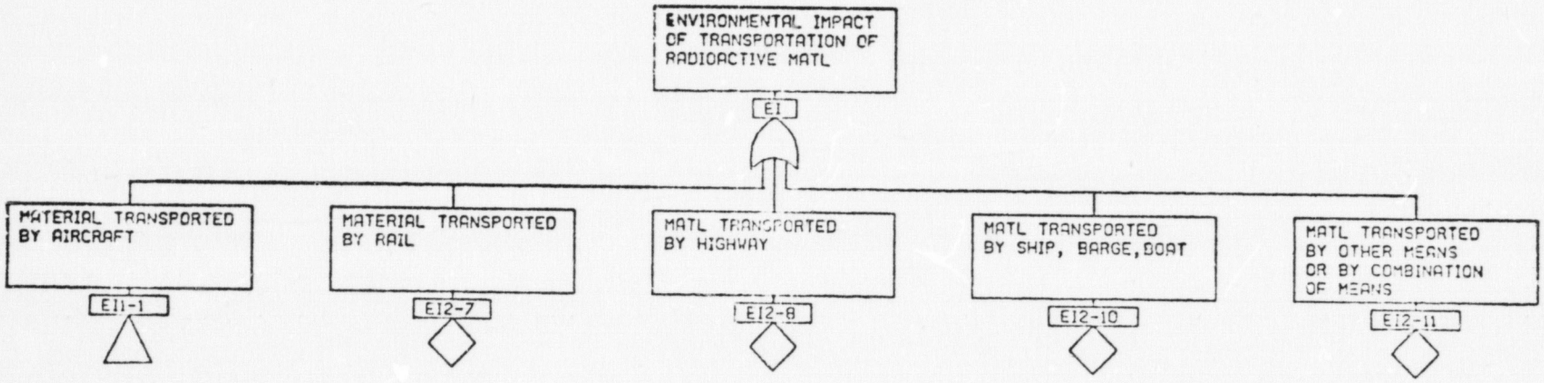


FIGURE A-1

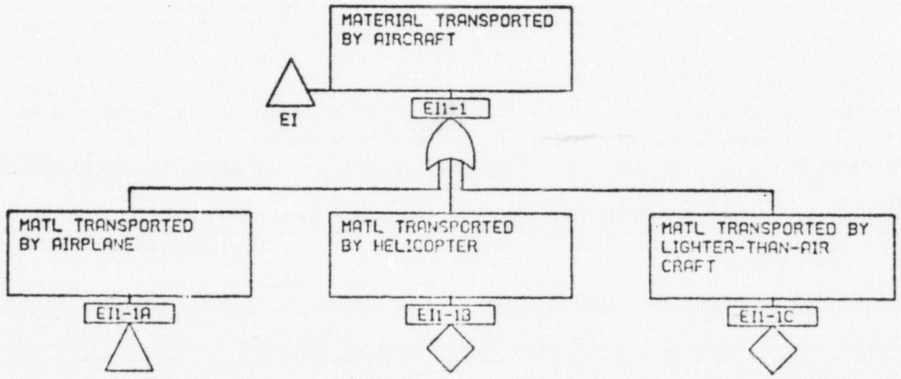


FIGURE A-2

Figure A-3, subdivides one given type of aircraft (airplanes) into the specific operations of air shipment. Environmental impact during the landing/takeoff operation is further broken down in subsequent tiers of the logic model not shown in this appendix. This impact may occur in a variety of ways: radiological exposure (at some presumably low dose rate) will occur with certainty during normal transportation by virtue of external penetrating radiation exposure to crewmen, cargo handlers, and the surrounding population; accidents may occur; malevolent acts (sabotage, hijacking, theft) could occur; etc. In each case, the development is carried from the impact-inducing scenario through the environmental consequence by expanding events in fault tree format and then integrating the effects which result from the basic events. An event might be a release-inducing crash, normal shipment, or the loss of a container, whereas an effect might be the person-rem resulting from a given accident. This approach permitted separate analyses of event probabilities and of radiological consequences to the environment.

III. Simplification of the Model

It was determined from the outset that the logic model should be both complete and quantifiable. To accomplish the first of these goals, sets of event and effect diagrams were drawn as discussed in Sections I and II.

Once the diagrams were fully developed, a critical review of all event scenarios and consequence models permitted reduction of the diagrams to more workable and quantifiable size. Guidance for the simplification process was obtained from transportation accident and mileage data, accident environment data, radiological consequence data, and current and projected radioactive material shipment data. In addition, the specific project goals were reviewed to insure that the scope of the

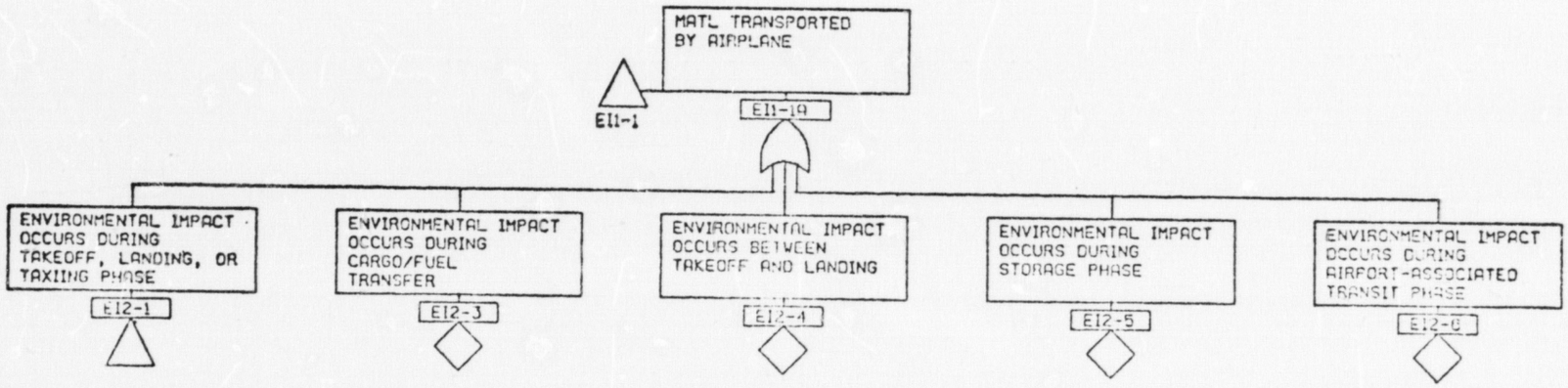

MATL TRANSPORTED BY AIRPLANE
E11-19
E11-1
ENVIRONMENTAL IMPACT OCCURS DURING TAKEOFF, LANDING, OR TAXIING PHASE
E12-1
ENVIRONMENTAL IMPACT OCCURS DURING CARGO/FUEL TRANSFER
E12-3
ENVIRONMENTAL IMPACT OCCURS BETWEEN TAKEOFF AND LANDING
E12-4
ENVIRONMENTAL IMPACT OCCURS DURING STORAGE PHASE
E12-5
ENVIRONMENTAL IMPACT OCCURS DURING AIRPORT-ASSOCIATED TRANSIT PHASE
E12-6

FIGURE A-3

model did not extend beyond the limits established. An effort was made to keep the simplified analysis model detailed enough so that various transportation schemes could be evaluated in light of new or ammended regulations. The following paragraphs outline the process by which the logic model presented in Section II of the appendix was reduced to the figures presented in the text of the report.

Initially, it was observed that the most significant radiological impacts where those that directly affected man. Radiological effects upon flora, fauna, and objects are orders of magnitude less than the direct impact to man and were therefore considered insignificant. The problem of ecochain build-up, e.g., the dose to man through radioactivity-contaminated food and water supplies, was also considered insignificant because ecochain build-up requires a continuous source of the contaminant. Since radioactivity would be released only in comparatively infrequent transportation accidents, such a continuous source does not exist. It was found that the only significant radiological effect to man due to normal transport is external penetrating radiation (gamma or neutron) and the only significant radiological effect to man due to an accident is from inhalation of the material (the case of external exposure from an accident involving special form shipments of radiography or teletherapy sources is addressed specifically in the text). Several other assumptions regarding doses, population densities, and weather were made as detailed in Chapters IV and V.

The next major simplication step was to break the original model into submodels to address the normal shipment and the various types of abnormal shipments; accidents, malevolent acts, etc. Each of these submodels was then modeled separately

in consonance with existing transportation and packaging data. It was noted that the detailed phase breakdown could be simplified into an "underway" scenario and an "in storage" scenario to optimize use of available data. The complexity of mode-link transfers is taken into account by a specific tabulation of mileages by mode for each scheme (see Chapter V). The myriad of actual industry shipments was simplifed to a list of standard shipments (see Chapter I) which was felt to best typify the current transportation scheme. This method has the inherent flexibility of being able to accept any scenario for analysis without changing the basic model.

The result of this simplification process is the logic model used for actual computation of environmental consequence which is shown in Chapters I, IV, V and VI of the text.

APPENDIX B - PLUTONIUM

A. Historial Background[1,2]

The element plutonium was first artifically formed by deuteron bombardment of uranium oxide:

$$_{92}U^{238} + {}_{1}H^{2} \xrightarrow{(16\ min)} {}_{93}Np^{238} + 2n$$

$$_{93}Np^{238} \xrightarrow[2.1\ days]{B-} {}_{94}Pu^{238}$$

This was performed in February 1941 by Arthur Wall, Glenn T. Seaborg, and Joseph Kennedy at the University of California at Berkeley (60-inch cyclotron). When the new element was shown to be fissionable in March 1941, the continuing research became shrouded in the secrecy of the Manhattan Project.

The initial focus of plutonium research was aimed at production of enough Pu-239 to manufacture a nuclear weapon. The only practical means of accomplishing this task was through the use of thermal reactors where neutron flux was sufficient to produce significant quantities of the material through the following capture/decay chain:

$$_{92}U^{238} + n \longrightarrow {}_{92}U^{239} \xrightarrow[23.5\ min]{(B-)} {}_{93}Np^{239} \xrightarrow[2.33\ days]{(B-)} {}_{94}Pu^{239}$$

With the advent of Atoms for Peace, the thrust of the plutonium research program became directed toward the possibilities of using Pu^{239} as a reactor fuel as well as exploiting the useful aspects of the other isotopes.

B. Chemistry and Metallurgy[3]

Plutonium is the fifth element in the actinide series. This series consists of elements whose chemical properties stem from partial vacancies in the 5f electron shell. Plutonium is a reactive silvery white metal which can exist in four valence states (+3, +4, +5, +6). It rapidly oxidizes in moist air, forming mixtures of oxides and hydrides.

Plutonium is attacked by all common gases at elevated temperatures and is soluble in most dilute acids and in most mineral acids and forms numerous organic and inorganic compounds.[3]

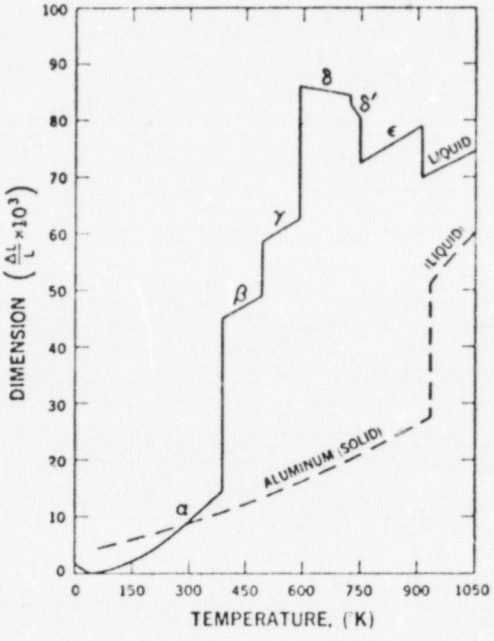
Metallurgically, plutonium is a very unusual metal. It exhibits six distinct allotropic phases (see Figure B-1), including two phases (δ and δ') with sharply decreasing values of $\frac{\Delta L}{L}$.

Plutonium is a very dense metal (19.86 gm/cm^3 for alpha phase) with a low melting point (640° C) and a very high boiling point (3327° C). It has a very low latent heat of fusion (680 cal/gm-atom) and is second only to manganese in magnitude of electrical resistivity (145 microhm -cm at room temperature).

C. Nuclear Properties[3,6]

Fifteen isotopes of plutonium, Pu-232 to Pu-246, have been identified. The most common isotope, Pu-239, has a 24,390 year half-life and decays by energetic alpha emission (4.64 to 4.16 mev).[4] This isotope is extensively used in nuclear weapons and is a potential fuel for nuclear reactors because of its high thermal neutron fission cross-section (740 barns). It is expected that Pu-239 will play a key role in the developing breeder reactor technology.

EXPANSION BEHAVIOR OF PLUTONIUM



Idealized version of the expansion behavior of plutonium, showing approximate temperature ranges in which the allotropes or phases of plutonium normally exist. The effect of temperature on the dimensions of a plutonium specimen is also shown.

When plutonium is heated from a temperature near absolute zero (0°K or −273°C), it is in the alpha phase and shrinks slightly until 50°K (−223°C) is reached, then expands with further heating to 388°K (115°C). At this temperature the specimen transforms to the beta phase undergoing marked expansion at constant temperature.

With heating to 583°K (310°C), the specimen expands in the beta phase, during beta-to-gamma transition, in the gamma phase, and during gamma-to-delta transition. In the delta phase, however, the specimen shrinks while being heated. It also shrinks as it transforms to the delta-prime phase at 725°K (425°C), as it is heated in the delta-prime phase, and as it transforms to the epsilon phase at 753°K (480°C).

Above that temperature the specimen is in the epsilon phase, and expands during heating until the melting point is reached at 913°K (640°C). The specimen shrinks as it changes from solid to liquid, then expands as it is heated in the liquid state.

The dashed line represents the simpler, more normal expansion of aluminum.

Figure B-1. Expansion Behavior of Plutonium[1]

Pu-238 is another important plutonium isotope. Because of its energetic alpha particles (4.7 to 5.5 mev[4]) and relatively short half-life (86.4 years), it has been used as an isotopic heat source for thermoelectric power generation devices such as the SNAP systems (used in lunar missions) and cardiac pacemakers.[5]

Through neutron capture by ^{239}Pu the higher isotopes of plutonium are formed. Principally, these isotopes are ^{240}Pu, ^{241}Pu, and ^{242}Pu. Of these three, Pu-241 is a relatively short-lived (13 years) beta emitter whose daughter product, americium-241 is used in neutron sources. Am-241 is a relatively long-lived (458 years) alpha emitter which constitutes a radiological health hazard comparable to Pu-239 on a dose/gram basis.

For the purposes of this study, the plutonium shipped was considered as light-water reactor (LWR) produced plutonium. Using values for LWR fuel irradiated to 35,000 mwd/MT[12], the values for isotopic composition shown in Table B-1 are obtained. Using the specific activities of the various alpha-emitting isotopes as shown in Table B-2 and rem/curie values from reference 9 (see Table III-8 in text), a ratio of 11.2 is obatined for $\frac{\text{reactor plutonium dose per gram inhaled}}{\text{pure Pu-239 dose per gram inhaled}}$. This is in agreement with the upper limit suggested by Cohen for high-burnup LWR fuel[16].

D. Biological Pathways

Very little data exists concerning the actual behavior of plutonium in humans. However, a large amount of data has been gathered concerning behavior in various animals (dogs, rats, pigs, sheep, primates), and inferences can be drawn from these

TABLE B-1

Isotopic Content of Plutonium in High Burn-up LWR Fuel* 1 Year After Reprocessing[12]

Isotope	Weight Percent
Pu-238	1.9%
Pu-239	63.0%
Pu-240	19.0%
Pu-241	12.0%
Pu-242	3.8%
Am-241	0.6%

*Yankee fuel irradiated to 35,000 mwd/MT

TABLE B-2

Specific Activity of Plutonium Isotopes

Isotope	Specific Activity (α) ci/gm	Specific Activity (β) ci/gm
Pu-238	17.1	-----
Pu-239	0.06	-----
Pu-240	0.228	-----
Pu-241	------	98.98
Pu-242	0.00382	-----
Am-241	3.43	-----

studies concerning behavior in humans. After deposition on skin, in wounds, in the gastrointestinal (GI) tract, or in the respiratory tract, plutonium may be transported by the blood or lymphatic systems to other organs or tissues of the body. The rate and amount of translocation is strongly dependent on the site of deposition and the physical and chemical properties of the plutonium compound[7].

D.1 Gastrointestinal Deposition

Only a small fraction of plutonium taken into the GI tract will be absorbed by the body. Experimental values range from 7×10^{-7} for PuO_2 to 1.9×10^{-2} for $Pu(NO_3)_4$[7]. The material that is absorbed is translocated mostly to skeletal structure and, to a lesser extent, to the liver. The amount of absorption appears to be strongly dependent on the valence of available Pu ions and on the pH of the administered solution. The maximum permissible concentration (MPC) for Pu in water set by the ICRP is based on .003% absorption which is conservative based on the pH data.

D.2 Skin Deposition

Intact skin presents a very effective barrier to plutonium absorption. In two cases where humans have been exposed to plutonium-bearing solutions with significant plutonium concentrations, absorption (as determined from urinalysis data) was less than .00002%[3]. If plutonium is introduced into a puncture wound, abrasion, or cut, a higher percentage (.3% to 2.7%) is absorbed[3]. The remainder is sloughed from the wound by normal healing and drainage processes. Most of the material absorbed from wounds is translocated to the liver.

D.3 Respiratory Deposition

The deposition and physiological effect of inhaled plutonium is very dependent on the aerodynamic character of the particles

and on the relative solubility of the compound inhaled. Figure B-2 shows the available pathways and body translocation mechanisms.

Large particles (> 10 micrometers in diameter) are filtered out of the inspired air by the cilia in the nasopharyngeal passages. They are captured in the mucoid lining of the passages, sloughed with the mucus drainage, and eventually swallowed (pathway b on Figure B-2). Intermediate sized particles (between 3 and 10 micrometers in diameter) are deposited in the tracheobronchial region. These particles also become entrained in the mucoid lining and are moved upward toward the pharynx by muco-ciliary action for eventual deposition into the upper GI tract (paghway d in Figure B-2). Small particles (less than 3 micrometers in diameter) pass into the pulmonary region and are candidates for pulmonary deposition.[11] The particles come in direct contact with the alveoli and are rapidly phagocytized and localized in the reticuloendothelial cells of the alveoli.[7]

Soluble plutonium readily diffuses from the reticulendothelial cells of the alveoli into the blood and lymphatic systems and is translocated into skeletal and liver tissue with a clearance half-time of 150-200.[7]

Insoluble plutonium, notably PuO_2, has a much longer lung clearance half-time (200-1000 days). Clearance mechanisms include tracheobronchial muco-ciliary action (pathway f on Figure B-2), some solubilization (pathway e on Figure B-2) and lymphatic absorption (pathway g on Figure B-2). The overall pattern of the plutonium translocation is shown on Figure B-3. The building in the thoracic lymph nodes appears to be an endpoint in that there is very little movement of the plutonium from the thoracic lymph nodes to the blood system (pathway h on Figure B-2).

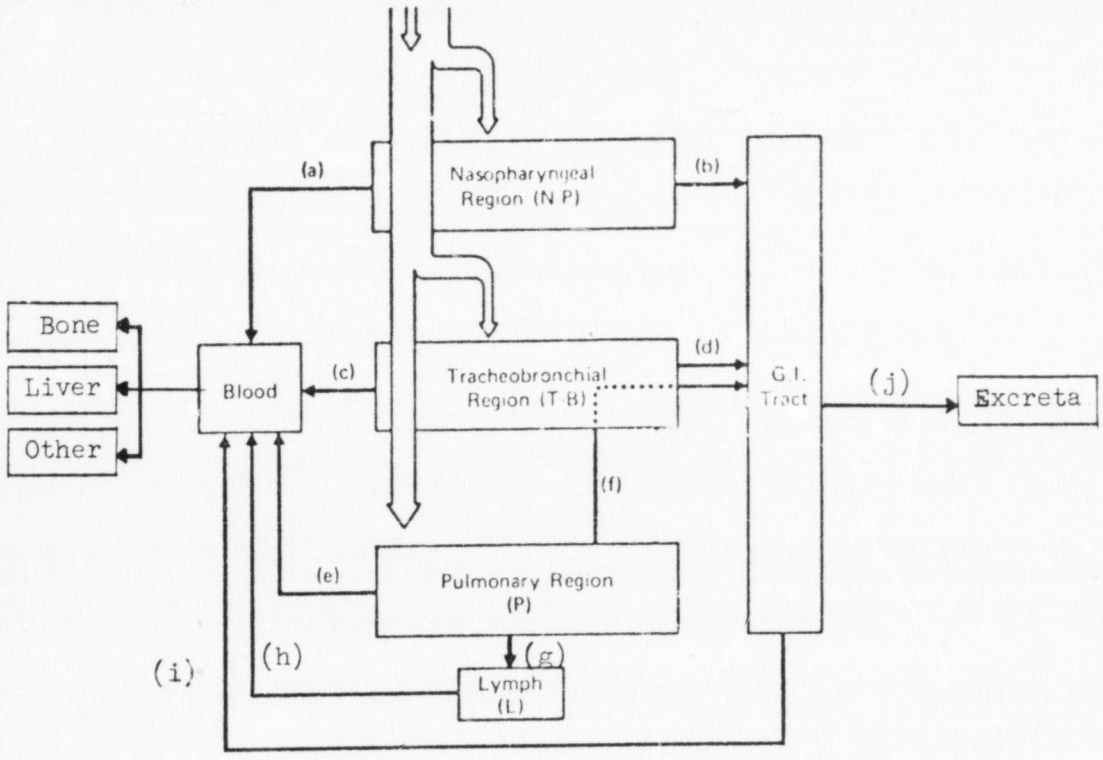


Figure B-2. Biological Pathways for Inhaled Material[8, 9, 10]

(a) Nasopharyngeal absorption to systemic blood

(b) Muco-ciliary action to upper GI tract

(c) Tracheobronchial absorption to systemic blood

(d) Muco-ciliary action to upper GI tract

(e) Alveolar diffusion

(f) Muco-ciliary action of phagocytized material to tracheobronchial region

(g) Lymphatic absorption

(h) Transfer to venous system

(i) Gastrointestinal absorption to systemic blood

(j) Excretion from GI tract as feces or absorption and excretion as urine

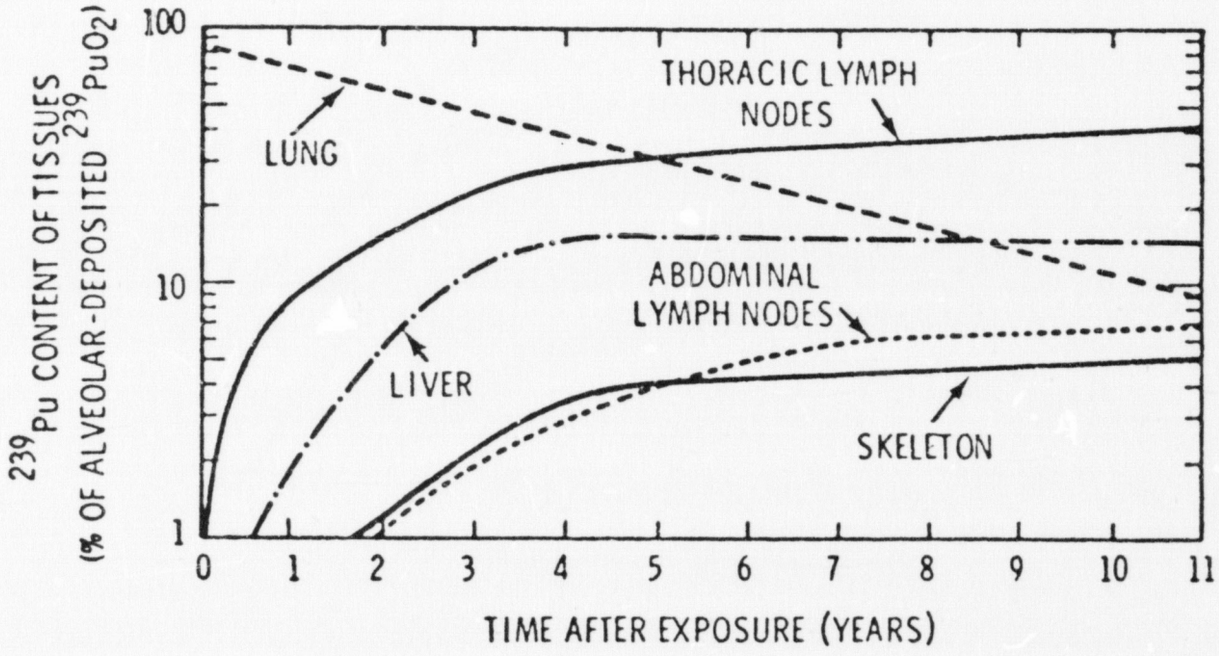


Figure B-3. Translocation of Pulmonary-Deposited Pu^{239} in Beagle Dogs[7]

Studies indicate[7] that Pu-239 and Pu-238 exhibit different biological behavior. The Pu-238 is translocated faster due to particle disintegration or surface fragmentation apparently caused by the higher specific activity within a given particle (17.4 ci/gm for Pu-238, .0614 ci/gm for Pu-239).[7]

E. Biological Effects

The effects of plutonium on tissue are largely a function of the high energy alpha and beta radiation emitted during radioactive decay.* Because of the ionic nature of alpha and beta radiation, energy deposition occur over only a few microns of body tissue. In large enough doses, this energy deposition can result in early effects ranging from illness to death. In smaller doses, the radiation appears to act as a carcinogenic agent. Cancers have been induced in laboratory animals, although no cancers attributable to plutonium have been observed in humans. The human data base includes 27 Los Alamos Scientific Laboratory personnel who were exposed to plutonium during the early phases of the nuclear weapons program. In spite of relatively high body burdens (.00007 to .09 microcuries), none of these people has shown any evidence of radiation injury.[3]

E.1 Effects on Skeletal and Hematopoietic Systems[3,7,8]

Very large bone accumulations of plutonium result in suppressed osteogenesis and eventual tissue necrosis. At lower doses, pathological bone fractures occur. At low doses, the incidence of osteogenic sarcoma shows a marked increase. All of these effects are on the skeletal tissue itself. The effect on hematopoietic tissue within the bone structure can result in depression of granular leukocytes at low doses and lymphphenia at higher doses. Leukemia incidence is not well established -- results from canine experiments show no increase while results from rats did show an increase.

*In the case of Pu-242, the toxicity is more a function of heavy metal poisoning vice radiation because of the very long half-life.

E.2 Effect on Liver

Very low doses of plutonium to the liver appear to have no effect in laboratory animals.[7] As the dose increases, bile duct tumors, and cirrhosis have been observed. The correlation of liver results from animals to man remains somewhat unclear at at this time.[7]

E.3 Effects on Lungs

Large deposits of plutonium (0.5 ci/gm of lung) in pulmonary tissue cause severe inflammation, edema, hemorrhage, and death within a relatively short period of time (1 week). At somewhat lower doses (0.05 - 0.1 ci/gm of lung) pulmonary fibrosis occurs, resulting in respiratory insufficiency and eventual death. At lower doses, various types of malignant tumors may develop.

E.4 Effect on Lymph Nodes

It has been concluded from the rodent and dog experiments that the lumph nodes are not especially susceptible to the carcinogenic action of alpha radiation from plutonium.[7]

F. Mitigation of Plutonium Contamination

Several techniques have been developed to mitigate the effects of plutonium exposure. The most common method involves intraveous injection of DTPA (diethylenetinaminepentacetic acid). This acid forms stable plutonium complexes and increases urinary excretion, in some cases by orders of magnitude.

In cases involving insoluble pulmonary plutonium deposits, pulmonary lavage with physiological saline has been used with some success. This is a dangerous medical procedure, however, so the actual hazard of the deposited material must be carefully examined.

G. Toxicity

Plutonium has been called "the most toxic substance known to man." There is no question that it is an extremely toxic material and that it can cause substantial damage to the body.

Reference 10 lists the median lethal dose of plutonium as 260 micrograms. This compares with median lethal dose for the currently stockpiled nerve gas sarin of 1000 micrograms and median lethal doses for botulism or anthrox spores in the submicrogram-to-microgram range. In terms of short-term deaths (within 60 days), the LC50 (lethal concentration for 50% of people exposed) for plutonium is 1.8 mg/m^3. Comparable values for cadmium fumes are 10 mg/m^3; for mercury vapor, 30 mg/m^3; and for phosgene, 65 mg/m^3.(10)

Although plutonium is certainly a potentially dangerous material, it is not orders of magnitude more potent than numerous other existing materials.

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12. Generic Environmental Statement on Mixed-Oxide Fuel

APPENDIX C

Incidents Reported to DOT Involving Radioactive Materials
(Sorted by Report Number)

APPENDIX C. Incidents Reported to DOT Involving Radioactive Materials (Sorted by Report Numbers)

COMMODITY	CODE	CONT 1	CONT 2	FAILURE 1	FAILURE 2	# FAIL	# SHIP	SP NO.	REPORT NO.
RADIOACTIVE MATERIA	08930	DRUM MTL		EXT PUNCT	OTHER	0	2	SP6000	1020027A
ZIRCONIUM SCRAP(POR	11000			BODY-SIDE	OTHER	1	1		1030104A
UNKN	00000	TANK CAR		**********	**********	1	1		1050096A
QUES	00000			**********	**********	0	1		1080013A
UNKN	00000	DRUM MTL		OTHER	**********	1	44		1080113A
RADIOACTIVE DEVICES	08910			LOOSE FVC	**********	1	1		1100076A
RADIOACTIVE DEVICES	08910	BOX WOOD		EXT PUNCT	OTHER	1	4	SP5248	1110107A
RADIOACTIVE MATERIA	08930	CONT LD		**********	**********	0	1		1120173A
RADIOACTIVE MATERIA	08930			OTHER	**********	0	2		2010126A
RADIOACTIVE MATERIA	08930	CYL MTL	BOX WOOD	LOOSE FVC	**********	1	1		2010137A
RADIOACTIVE MATERIA	08930	CONT PLS	6D	**********	**********	1	29		2010193A
RADIOACTIVE MATERIA	08930	CONT LD	BOX FBR	DROPPED	**********	1	1		2020138A
RADIOACTIVE MATERIA	08940			**********	**********	0	0		2030227A
FISSILE RADIOACTIVE	05110	DRUM MTL		EXT PUNCT	**********	1	6		2040118A
RADIOACTIVE MATERIA	08930	BOX WOOD		OTHER	**********	1	1		2040228A
RADIOACTIVE MATERIA	08930	TUBE GLS	TUBE FBR	DROPPED	**********	2	2		2050044A
RADIOACTIVE MATERI	08920	TANK TRK		EXT PUNCT	FREEZING	1	1		2070120A
RADIOACTIVE MATERIA	08930	LINR FLS	DRUM MTL	INT PRESS	CORR-RUST	1	4		2070391A
RADIOACTIVE MATERIA	08930	CYL MTL	7A	OTHER	**********	1	5		2070390A
RADIOACTIVE MATERIA	08930		BOX WOOD	OTHER FRT	**********	1	1		2080001A
RADIOACTIVE MATERIA	08920	17H		INNER REC	BOTTOM	1	9		2090377A
RADIOACTIVE MATERIA	08930	CYL MTL		LOOSE FVC	**********	1	1		2100089A
RADIOACTIVE MTATERI	08920	BOX MTL	BOX WOOD	EXT HEAT	**********	4	74		2100393A
RADIOACTIVE MTATERI	08920	17H		WELD	**********	1	57		2120196A
RADIOACTIVE MATERIA	08930	DRUM MTL		OTHER FRT	LOOSE FVC	0	10		2130244A
RADIOACTIVE MATERIA	08930	DRUM MTL		OTHER FRT	LOOSE FVC	4	10		3010116A
RADIOACTIVE MATERIA	08930	PAIL MTL		DEF FVC	LOOSE FVC	2	22		3010262A
RADIOACTIVE MTATERI	08920	BAG PPR		EXT PUNCT	**********	1	1K		3030098A
R.A.M. N.O.S.	08930	CAN MTL	BOX FBR	DROPPED		1	1		3070241A
R.A.M. N.O.S.	08930	21C		EXT PUNCT	BOTTOM	1	1		3070270A
R.A.M. SMALL QUANTY	08940	BOTL GLS	21C	OTHER FRT		1	4		3080530A
R.A.M. LOW SPEC ACT	08920	DRUM MTL		CORR-RUST		1	21		3100029A
R.A.M. N.O.S.	08930	CYL MTL	12B	DROPPED	BOTTOM	1	1		3100274A
R.A.M. LOW SPEC ACT	08920	17H		DROPPED		1	53		3110050A
RADIOACTIVE DEVICES	08910	BOX FBR		OTHER LIQ		1	1		3110179A
R.A.M. LOW SPEC ACT	08920	17H		EXT PUNCT		2	79		3120045A
R.A.M. LOW SPEC ACT	08920	DRUM MTL		CORR-RUST	BODY-SIDE	1	62		4020091A
RADIOACTIVE DEVICES	08910	BOX WOOD		OTHER FRT	OTHER	1	1		4020263A
R.A.M. N.O.S.	08930	CAN MTL	21C	OTHER		1	1		4020294A
R.A.M. N.O.S.	08930	BLANK		BOTTOM	BODY-SIDE	1	1		4030098A
R.A.M. N.O.S.	08930	7A		DROPPED	OTHER	1	1		4030170A
R.A.M. N.O.S.	08930	BOX FBR		WATER		0	6		4030232A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	1		4030399A
R.A.M. N.O.S.	08930	DRUM MTL		EXT PUNCT	OTHER	2	0		4030476A
R.A.M. LOW SPEC ACT	08920	TANK PRT		OTHER		0	13		4040129A
R.A.M. N.O.S.	08930	CAN MTL		OTHER		1	1		4040132A
R.A.M. N.O.S.	08930	CAN MTL		OTHER		1	1		4040132B
R.A.M. N.O.S.	08930	55		OTHER		1	1		4040403A
R.A.M. N.O.S.	08930	12B		DROPPED	EXT PUNCT	0	12		4040404A
R.A.M. N.O.S.	08930	7A		DROPPED		1	2		4050132A

COMMODITY	CODE	CONT 1	CONT 2	FAILURE 1	FAILURE 2	# FAIL	# SHIP	SP NO.	REPORT NO.
R.A.M. N.O.S.	08930	BLANK		OTHER		1	1	SP5874	4050139A
R.A.M. N.O.S.	08930	BLANK		OTHER		1	1	SP5874	4050140A
R.A.M. N.O.S.	08930	BLANK		OTHER		1	1	SP5874	4050141A
R.A.M. N.O.S.	08930	7A		DROPPED	OTHER FRT	0	1		4050229A
R.A.M. N.O.S.	08930	CONT STY	12B	OTHER		1	1		4050255A
R.A.M. N.O.S.	08930	BOTL GLS	TUBE FBR	DROPPED	EXT PUNCT	1	2		4050486A
R.A.M. SPEC. FORM	08950	DRUM MTL		BOTTOM		0	1		4060104A
R.A.M. N.O.S.	08930	7A		OTHER		1	1		4060105A
R.A.M. N.O.S.	08930	BOX FBR		EXT PUNCT		0	1		4060234A
R.A.M. N.O.S.	08930	17E		CRIME		1	11		4060680A
R.A.M. N.O.S.	08930			WATER		0	2		4060683A
R.A.M. N.O.S.	08930	12B		DROPPED		0	1		4070266A
R.A.M. N.O.S.	08930	CONT PLS	BOX FBR	DROPPED		1	19		4070349A
R.A.M. N.O.S.	08930	TANK PRT		OTHER		1	1	SP5660	4070362A
FISSILE R.A.M.	05110	DRUM MTL		EXT PUNCT	OTHER	0	70		4070629A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	2		4070739A
R.A.M. N.O.S.	08930	CAN MTL	BOX FBR	DROPPED		0	1		4070805A
R.A.M. SMALL QUANTY	08940	BOX FBR		BODY-SIDE		3	3		4070846A
R.A.M. N.O.S.	08930	BLANK	12B	OTHER		1	2		4080265A
R.A.M. N.O.S.	08930	BOX MTL	BOX WOOD	OTHER FRT		0	6		4080493A
R.A.M. N.O.S.	08930	BOX MTL	BOX FBR	WATER	BODY-SIDE	1	4		4080497A
R.A.M. N.O.S.	08930	BOX MTL	BOX FBR	OTHER FRT		1	1		4080630A
R.A.M. LOW SPEC ACT	08920	TYPE B		DROPPED		0	1		4080679A
R.A.M. N.O.S.	08930	LINR PLS	BOX FBR	OTHER		0	3		4080698A
R.A.M. N.O.S.	08930	BLANK	BOX FBR	DROPPED		1	1		4080789A
R.A.M. LOW SPEC ACT	08920	TANK PRT		OTHER		0	1		4080947A
R.A.M. N.O.S.	08930	BOTL GLS	BOX FBR	EXT PUNCT		1	1		4090003A
R.A.M. N.O.S.	08930	DRUM MTL		EXT PUNCT		0	1		4090112A
R.A.M. N.O.S.	08930	BOTL PLS	7A	OTHER		1	1		4090307A
THORIUM NITRATE SOL	10270	21C		DROPPED		1	24		4090323A
R.A.M. SPEC. FORM	08950	55		OTHER		1	1		4090359A
R.A.M. N.O.S.	08930	CAN MTL	DRUM MTL	LOOSE FVC		1	1		4090529A
R.A.M. N.O.S.	08930	PAIL MTL		LOOSE FVC		1	2		4090721A
R.A.M. N.O.S.	08930	BLANK	12B	OTHER FRT		0	1		4090845A
R.A.M. SPEC. FORM	08950	BLANK	CAN MTL	CORR-RUST	BOTTOM	1	1		4100206A
R.A.M. SPEC. FORM	08950	55	BOX WOOD	OTHER FRT		1	1		4100433A
R.A.M. N.O.S.	08930	CAN MTL		EXT PUNCT	BODY-SIDE	1	3		4100585A
R.A.M. N.O.S.	08930	BLANK		DROPPED		0	0		4100655A
R.A.M. N.O.S.	08930	BOX MTL	BOX FBR	WATER		0	1		4110247A
R.A.M. N.O.S.	08930	15A	7A	LOOSE FVC	BOTTOM	1	2		4120197A
R.A.M. N.O.S.	08930	15A	7A	LOOSE FVC	BOTTOM	1	21		4120197B
R.A.M. N.O.S.	08930	BOTL	7A	EXT PUNCT	OTHER FRT	0	3		4120235A
R.A.M. N.O.S.	08930	BOTL	7A	EXT PUNCT	OTHER FRT	0	2		4120235B
R.A.M. N.O.S.	08930	TYPE B				0	1	SP5874	4120390A
R.A.M. N.O.S.	08930	7A		OTHER		1	1		4120628A
R.A.M. SPEC. FORM	08950	CAN MTL	BOX FBR	DEF FVC		0	2		4120638A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	1		4120646A

APPENDIX D-1
NUCLEAR REGULATORY COMMISSION

10 CFR 71. Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions

PART 71

PACKAGING OF RADIOACTIVE MATERIAL FOR TRANSPORT AND TRANSPORTATION OF RADIOACTIVE MATERIAL UNDER CERTAIN CONDITIONS *

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Appendices

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AUTHORITY: The provisions of this Part 71 issued under secs. 53, 63, 81, 161, 182, 183, 68 Stat. 930, 933, 935, 948, 953, 954, as amended; 42 U.S.C. 2073, 2093, 2111, 2201, 2232, 2233, unless otherwise noted. For the purposes of sec. 223, 68 Stat. 958, as amended; 42 U.S.C. 2273, §§ 71.61—71.63 issued under sec. 1610, 68 Stat. 950, as amended; 42 U.S.C. 2201(o). Secs. 202, 206, Pub. L. 93-438, 88 Stat. 1244, 1246; 42 U.S.C. 5842, 5846.

38 FR 10437

§ 71.1 Purpose.

(a) This part establishes requirements for transportation and for preparation for shipment of licensed material and prescribes procedures and standards for approval by the Nuclear Regulatory Commission of packaging and shipping procedures for fissile material (uranium-233, uranium-235, plutonium-238, plutonium-239, and plutonium-241) and for quantities of licensed materials in excess of type A quantities, as defined in § 71.4(q), and prescribes certain requirements governing such packaging and shipping.

(b) The packaging and transport of these materials are also subject to other parts of this chapter and to the regulations of other agencies having jurisdiction over means of transport. The requirements of this part are in addition to, and not in substitution for, other requirements.

37 FR 3985

§ 71.2 Scope.

The regulations in this part apply to each person authorized by specific license issued by the Commission to receive, possess, use or transfer licensed materials, if he delivers such materials to a carrier for transport or transports such material outside the confines of his plant or other place of use.

§ 71.3 Requirement for license.

No licensee subject to the regulations in this part shall (a) deliver any licensed materials to a carrier for transport or (b) transport licensed material except as authorized in a general license or specific license issued by the Commission, or as exempted in this part.

31 FR 9941

§ 71.4 Definitions.

As used in this part:

(a) "Carrier" means any person engaged in the transportation of passengers or property, as common, contract, or private carrier, or freight forwarder, as those terms are used in the Interstate Commerce Act, as amended, or the U.S. Post Office;

(b) "Close reflection by water" means immediate contact by water of sufficient thickness to reflect a maximum number of neutrons;

(c) "Containment vessel" means the receptacle on which principal reliance is placed to retain the radioactive material during transport;

(d) "Fissile classification" means classification of a package or shipment of fissile materials according to the controls needed to provide nuclear cri-

*Amended 37 FR 3985.

ticality safety during transportation as follows:

(1) Fissile Class I: Packages which may be transported in unlimited numbers and in any arrangement, and which require no nuclear criticality safety controls during transportation. For purposes of nuclear criticality safety control, a transportation index is not assigned to Fissile Class I packages. However, the external radiation levels may require a transport index number.

(2) Fissile Class II: Packages which may be transported together in any arrangement but in numbers which do not exceed an aggregate transport index of 50. For purposes of nuclear criticality safety control, individual packages may have a transport index of not less than 0.1 and not more than 10. However, the external radiation levels may require a higher transport index number but not to exceed 10. Such shipments require no nuclear criticality safety control by the shipper during transportation.

(3) Fissile Class III: Shipments of packages which do not meet the requirements of Fissile Classes I or II and which are controlled in transportation by special arrangements between the shipper and the carrier to provide nuclear criticality safety.

(e) "Fissile materials" means uranium-233, uranium-235, plutonium-238, plutonium-239, and plutonium-241;

(f) "Large quantity" means a quantity of radioactive material, the aggregate radioactivity of which exceeds any one of the following:

(1) For transport groups as defined in paragraph (p) of this section:

(i) Group I or II radionuclides: 20 curies;

(ii) Group III or IV radionuclides: 200 curies;

(iii) Group V radionuclides: 5,000 curies;

(iv) Group VI or VII radionuclides: 50,000 curies;

and

(2) For special form material as defined in paragraph (o) of this section: 5,000 curies.

(g) "Low specific activity material" means any of the following:

(1) Uranium or thorium ores and physical or chemical concentrates of those ores;

(2) Unirradiated natural or depleted uranium or unirradiated natural thorium;

(3) Tritium oxide in aqueous solutions provided the concentration does not exceed 5.0 millicuries per milliliter;

(4) Material in which the activity is essentially uniformly distributed and in which the estimated average concentration per gram of contents does not exceed:

(i) 0.0001 millicurie of Group I radionuclides; or

(ii) 0.005 millicurie of Group II radionuclides; or

(iii) 0.3 millicurie of Groups III or IV radionuclides.

NOTE: This includes, but is not limited to, materials of low radioactivity concentration such as residues or solutions from chemical processing; wastes such as building rubble, metal, wood, and fabric scrap, glassware, paper, and cardboard; solid or liquid plant waste, sludges, and ashes.

(5) Objects of nonradioactive material externally contaminated with radioactive material, provided that the radioactive material is not readily dispersible and the surface contamination, when averaged over an area of 1 square meter, does not exceed 0.0001 millicurie (220,000 disintegrations per minute) per square centimeter of Group I radionuclides or 0.001 millicurie (2,200,000 disintegrations per minute) per square centimeter of other radionuclides.

(h) "Maximum normal operating pressure" means the maximum gauge pressure which is expected to develop in the containment vessel under the normal conditions of transport specified in Appendix A of this part;

(i) "Moderator" means a material used to reduce, by scattering collisions and without appreciable capture, the kinetic energy of neutrons;

(j) "Optimum interspersed hydrogenous moderation" means the occurrence of hydrogenous material between containment vessels to such an extent that the maximum nuclear reactivity results;

(k) "Package" means packaging and its radioactive contents;

(l) "Packaging" means one or more receptacles and wrappers and their contents excluding fissile material and other radioactive material, but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and for absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment;

(m) "Primary coolant" means a gas, liquid, or solid, or combination of them, in contact with the radioactive material or, if the material is in special form, in contact with its capsule, and used to remove decay heat;

(n) "Sample package" means a package which is fabricated, packed, and closed to fairly represent the proposed package as it would be presented for transport, simulating the material to be transported, as to weight and physical and chemical form;

(o) "Special form" means any of the following physical forms of licensed material of any transport group:

(1) The material is in solid form having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters; does not melt, sublime, or ignite in air at a temperature of 1,000° F.; will not shatter or crumble if subjected to the percussion test described in Appendix D of this part; and is not dissolved or converted into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68° F. or in air at 86° F.; or

(2) The material is securely contained in a capsule having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters, which will retain its contents if subjected to the tests prescribed in Appendix D of this part; and which is constructed of materials which do not melt, sublime, or ignite in air at 1,475° F., and do not dissolve or convert into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68° F. or in air at 86° F.

(p) "Transport group" means any one of seven groups into which radionuclides is normal form are classified, according to their toxicity and their relative potential hazard in transport, in Appendix C of this part.

(1) Any radionuclide not specifically listed in one of the groups in Appendix C shall be assigned to one of the Groups in accordance with the following table:

Radionuclide	Radioactive half-life		
	0 to 1000 days	1000 days to 10^4 years	Over 10^4 years
Atomic number 1-81	Group III	Group II	Group III
Atomic number 82 and over	Group I	Group I	Group III

(2) For mixtures of radionuclides the following shall apply:

(i) If the identity and respective activity of each radionuclide are known, the permissible activity of each radionuclide shall be such that the sum, for all groups present, of the ratio between the total activity for each group to the permissible activity for each group will not be greater than unity.

(ii) If the groups of the radionuclides are known but the amount in each group cannot be reasonably determined, the

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mixture shall be assigned to the most restrictive group present.

(iii) If the identity of all or some of the radionuclides cannot be reasonably determined, each of those unidentified radionuclides shall be considered as belonging to the most restrictive group which cannot be positively excluded.

(iv) Mixtures consisting of a single radioactive decay chain where the radionuclides are in the naturally occurring proportions shall be considered as consisting of a single radionuclide. The group and activity shall be that of the first member present in the chain, except that if a radionuclide "x" has a half-life longer than that of that first member and an activity greater than that of any other member, including the first, at any time during transportation, the transport group of the nuclide "x" and the activity of the mixture shall be the maximum activity of that nuclide "x" during transportation.

33 FR 1762

Terms defined in Parts 20, 30 to 36 inclusive, and 70 of this chapter have the same meaning when used in this part.

31 FR 9941

(q) "Type A quantity" and "type B quantity" means a quantity of radioactive material the aggregate radioactivity of which does not exceed that specified in the following table:

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Transport groups see § 71.4(p)	Type A quantity (in curies)	Type B quantity (in curies)
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5,000
VI and VII	1,000	50,000
Special form	1 20	5,000

37 FR 3985

§ 71.5 Transportation of licensed material.

38 FR 10437

(a) No licensee shall transport any licensed material outside of the confines of his plant or other place of use, or deliver any licensed material to a carrier for transport, unless the licensee complies with the applicable requirements of the regulations appropriate to the mode of transport, of the Department of Transportation in 49 CFR Parts 170-189, 14 CFR Part 103 and 46 Part 146, and the U.S. Postal Service in 39 CFR Parts 14 and 15 insofar as such regulations relate to the packaging of byproduct, source, or special nuclear material, marking and labeling of the packages, loading and storage of packages, placarding of the transportation vehicle, monitoring requirements and accident reporting.

37 FR 3985

(b) When Department of Transportation regulations are not applicable to shipments of licensed material by rail, highway, or water because the shipment or the transportation of the shipment is not in interstate or foreign commerce, or to shipments of licensed material by air because the shipment is not transported in civil aircraft, the licensee shall conform to the standards and requirements of the Department of Transportation specified in paragraph (a) of this section, to the same extent as if the shipment or transportation were in interstate or foreign commerce or in civil aircraft. Any requests for modifications, waivers, or exemptions from those requirements, and any notifications referred to in those requirements shall be filed with or made to, the Nuclear Regulatory Commission.

(c) Paragraph (a) of this section shall not apply to the transportation of licensed material, or to the delivery of licensed material to a carrier for transport, where such transportation is subject to the regulations of the Department of Transportation or the U.S. Postal Service.

EXEMPTIONS

31 FR 9941

•§ 71.6 Specific exemptions.

On application of any interested person or on its own initiative, the Commission may grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not endanger life or property or the common defense and security.

37 FR 3985

•§ 71.7 Exemption for no more than Type A quantities.†

38 FR 10437

A licensee is exempt from all the requirements of this part to the extent that he delivers to a carrier for transport:

Packages each of which contains no licensed material having a specific activity in excess of 0.002 microcurie/gram; or

(b) Shipments subject to the regulations of the Department of Transportation in 49 CFR parts 170—189, 14 CFR part 103, or 46 CFR part 146 or the U.S. Postal Service in 39 CFR parts 14 and 15 of packages each of which contains no more than a type A quantity of radioactive material, as defined in § 71.4(q), which may include one of the following:

(1) Not more than 15 grams of fissile material; or

(2) Thorium, or uranium containing not more than 0.72 percent by weight of fissile material; or

(3) Uranium compounds, other than metal (e.g., UF_4, UF_6, or uranium oxide in bulk form, not pelletted or fabricated into shapes) or aqueous[1] solutions of uranium, in which the total amount of uranium-233 and plutonium present does not exceed 1.0‡ percent by weight of the uranium-235 content, and the total fissile content does not exceed 1.00‡ percent by weight of the total uranium content; or

(4) Homogenous hydrogenous[2] solutions or mixtures containing not more than:

38 FR 10437

(i) 500 grams of any fissile material, provided the atomic ratio of hydrogen to fissile material is greater than 7,600; or

(ii) 800 grams of uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of other fissile material is not more than 1 percent by weight of the total uranium-235 content; or

(iii) 500 grams of uranium-233 and uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of plutonium is not more than 1 percent by weight of the total uranium-233 and uranium-235 content; or

(5) Less than 350 grams of fissile material: *Provided*, That there is not more than 5 grams of fissile material in any cubic foot within the package.

37 FR 3985

•§ 71.8 Exemption of physicians.

Physicians, as defined in § 35.3(b) of this chapter, are exempt from the regulations in this part to the extent that they transport licensed material for use in the practice of medicine.

38 FR 10437

§ 71.9 Exemption for fissile material.

A licensee is exempt from requirements in §§ 71.33, 71.35(b), 71.36(b) 71.37, 71.38, 71.39, and 71.40 to the extent that he delivers to a carrier for transport packages each of which contains one of the following:

(a) Not more than 15 grams of fissile material; or

(b) Thorium, or uranium containing not more than 0.72 percent by weight of fissile material; or

(c) Uranium compounds, other than metal (e.g., UF_4, UF_6, or uranium oxide

Except that for californium-252, the limit is 2 Ci.

•Redesignated by 38 FR 10437.

†Amended 38 FR 10

[1] This applies to light water and does not apply to heavy water.

[2] This applies to light hydrogen and does not apply to heavy hydrogen (i.e., deuterium or tritium).

‡ Amended 38 FR 16347

in bulk form not pelletted or fabricated to shapes) or aqueous solutions of uranium, in which the total amount of uranium-233 and plutonium present does not exceed 1.0‡ percent by weight of the uranium-235 content, and the total fissile content does not exceed 1.00‡ percent by weight of the total uranium content; or

(d) Homogeneous hydrogenous[2] solutions or mixtures containing not more than:

(1) 500 grams of any fissile material, provided the atomic ratio of hydrogen to fissile material is greater than 7,600; or

(2) 800 grams of uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of other fissile material is not more than 1 percent by weight of the total uranium-235 content; or

(3) 500 grams of uranium-233 and uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of plutonium is not more than 1 percent by weight of the total uranium-233 and uranium-235 content; or

(e) Less than 350 grams of fissile material: *Provided*, That there is not more than 5 grams of fissile material in any cubic foot within the package.

38 FR 10437

§ 71.10 Limited exemption for shipment of type B quantities of radioactive material.

A person delivering a type B quantity of radioactive material, as defined in § 71.4(q), to a carrier for transport in accordance with the provisions of a special permit, which has been issued by the Department of Transportation and is in effect on June 30, 1973, is exempt from the requirements in this part with respect to such shipments. The exemption granted by this section shall terminate on December 31, 1973, or on the date on which the DOT special permit expires, whichever is later, except as to activities described both in the special permit and in an application for a license which the person has, prior to the termination date of the exemption, filed with the Commission. If the person has filed such an application, the exemption granted by this section shall continue until the application has been finally determined by the Commission.

GENERAL LICENSES**

*§ 71.11 General license for shipment of licensed material.

31 FR 9941

A general license is hereby issued, to persons holding specific licenses issued pursuant to this chapter, to deliver licensed material to a carrier for transport, without complying with the package standards of Subpart C of this part, when either:

(a) The material is shipped as a Fissile Class III shipment with the following limitations on its contents:

38 FR 10437

(1) No single package contains more than a type A quantity of radioactive material, as defined in § 71.4(q); and

31 FR 9941

38 FR 10437

(2) The fissile material contents of the shipment do not exceed:

(i) 500 grams of uranium-235; or

(ii) 300 grams total of uranium-233, plutonium-238, plutonium-239, and plutonium-241; or

(iii) Any combination of uranium-233, uranium-235, and plutonium in such quantities that the sum of the ratios of the quantity of each of them to the quantity specified in subdivisions (i) and (ii) of this subparagraph does not exceed unity; or

(iv) 2500 grams of plutonium-238, plutonium-239, and plutonium-241 encapsulated as plutonium-beryllium neutron sources, with no one package containing in excess of 400 grams of plutonium-238, plutonium-239, and plutonium-241; or

(b) The material is shipped as Fissile Class II packages with the following limitations on the contents of each package:

38 FR 10437

(1) No single package contains more than a type A quantity of radioactive material, as defined in § 71.4(q); and

(2) No package contains fissile material in excess of the amounts specified in the following table, and each package is labeled with the corresponding transport index:

Maximum quantity of fissile material in a single package				Corresponding transport index
U-235 (grams)	U-233 (grams)	Plutonium (grams)	Plutonium as Pu-Be neutron sources (grams)	
35-40	27-30	23-25	320-400	10
30-35	24-27	21-23	240-320	8
25-30	21-24	19-21	160-240	6
20-25	18-21	17-19	80-160	4
15-20	15-18	15-17	0-80	2

NOTE. Combinations of fissile materials are authorized. For combinations of fissile materials, the transport index is the sum of the individual corresponding transport indexes. The total transport index shall not exceed 10.

39 FR 22131

35 FR 6271

§ 71.12 General license for shipment in DOT specification containers, in packages approved for use by another person, and in packages approved by a foreign national competent authority.

A general license is hereby issued, to persons holding a general or specific license issued pursuant to this chapter, to deliver licensed material to a carrier for transport:

38 FR 10437

(a) In a specification container for fissile material as specified in § 173.396 (b) or (c) or for a type B quantity of radioactive material as specified in § 173.394(b) or § 173.395(b), or for a large quantity of radioactive material as specified in § 173.394(c) or § 173.395(c) of the regulations of the Department of Transportation, 49 CFR part 173; or

39 FR 32125

(b) In a package for which a license, certificate of compliance or other approval has been issued by the Commission's Director of Nuclear Material Safety and Safeguards or the Atomic Energy Commission, provided that:

(1) The person using a package pursuant to the general license provided by this paragraph:

(i) Has a copy of the specific license, certificate of compliance, or other approval authorizing use of the package and all documents referred to in the license, certificate, or other approval, as applicable;

(ii) Complies with the terms and conditions of the license, certificate, or other approval, as applicable, and the applicable requirements of this part; and

(iii) Prior to first use of the package submits in writing to the Director of Nuclear Material Safety and Safeguards or the Atomic Energy Commission, his name and license number, the name and license or certificate number of the person to whom the package approval has been issued, and the package identification number specified in the package approval.

(2) The package approval authorizes use of the package under general license provided in this paragraph.

38 FR 10437

(c) In a package which meets the pertinent requirements in the 1967 regulations of the International Atomic Energy Agency and the use of which has been approved in a foreign national competent

[1] This applies to light water and does not apply to heavy water.

[2] This applies to light hydrogen and does not apply to heavy hydrogen (i.e., deuterium or tritium).

**Added 38 FR 10437.

‡Amended 38 FR 16347.

*Redesignated 38 FR 10437.

38 FR 10437

authority certificate which has been revalidated by the Department of Transportation, *Provided*, That the person using a package pursuant to the general license provided by this paragraph:

(1) Has and complies with the applicable certificate, the revalidation, and the documents referenced in the certificate relative to the use and maintenance of the packaging, and the actions to be taken prior to shipment; and

(2) Complies with the applicable requirements of this part, and the Department of Transportation regulations in 49 CFR part 173, 14 CFR part 103, and 46 CFR part 146.

40 FR 8774

§ 71.13 Communications.

All communications concerning the regulations in this part should be addressed to the Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Director of Nuclear Material Safety and Safeguards, or may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C. or at 7920 Norfolk Avenue, Bethesda, Maryland.

31 FR 9941

***§ 71.14 Interpretations.**

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding on the Commission.

***§ 71.15 Additional requirements.**

The Commission may by rule, regulation, or order impose upon any licensee such requirements, in addition to those established in this part, as it deems necessary or appropriate to protect health or to minimize danger to life or property.

37 FR 3985

****§ 71.16 Amendment of existing licenses.**

(a) Licenses issued pursuant to this part and in effect on October 4, 1968, which authorize Fissile Class II packages are hereby amended by increasing the minimum number of units specified for each Fissile Class II package by a factor of 1.25. The new number, shall be rounded up to the first decimal. In addition, the term "radiation units" is changed to "transport index" wherever used in the license.

37 FR 3985

(b) The reference to § 71.7(b) in licenses issued pursuant to this part prior to March 26, 1972,** is changed to § 71.9(b).

38 FR 10437

(c) The reference to § 71.9(b) in licenses issued pursuant to this part prior to June 30, 1973, is changed to 71.12(b).

31 FR 9941

Subpart B—License Applications

§ 71.21 Contents of application.

An application for a specific license under this part may be submitted as an application for a license or license amendment under this chapter and shall include, for each proposed packaging design and method of transport, the following information in addition to any otherwise required:

(a) A package description as required by § 71.22;

(b) A package evaluation as required by § 71.23;

(c) A description of proposed procedural controls as required by § 71.24;

(d) In the case of fissile material, an identification of the proposed fissile class.

§ 71.22 Package description.

The application shall include a description of the proposed package in sufficient detail to identify the package accurately and to provide a sufficient basis for evaluation of the packaging. The description should include:

(a) With respect to the packaging:

(1) Gross weight;

(2) Model number;

(3) Specific materials of construction, weights, dimensions, and fabrication methods of:

(i) Receptacles, identifying the one which is considered to be the containment vessel;

(ii) Materials specifically used as nonfissile neutron absorbers or moderators;

(iii) Internal and external structures supporting or protecting receptacles;

(iv) Valves, sampling ports, lifting devices, and tie-down devices;

(v) Structural and mechanical means for the transfer and dissipation of heat; and

(4) Identification and volumes of any coolants and of receptacles containing coolant.

(b) With respect to the contents of the package:

(1) Identification and maximum radioactivity of radioactive constituents;

(2) Identification and maximum quantities of fissile constituents;

(3) Chemical and physical form;

(4) Extent of reflection, the amount and identity of non-fissile neutron absorbers in the fissile constitutents, and the atomic ratio of moderator to fissile constituents;

(5) Maximum weight; and

(6) Maximum amount of decay heat.

31 FR 9941

§ 71.23 Package evaluation.

The applicant shall:

(a) Demonstrate that the package satisfies the standards specified in Subpart C;

(b) For a Fissile Class II package, ascertain and specify the number of similar packages which may be transported together in accordance with § 71.39; and

(c) For a Fissile Class III shipment, describe any proposed special controls and precautions to be exercised during transport, loading, unloading, and handling, and in the event of accident or delay.

37 FR 3985

§ 71.24 Procedural controls.

The applicant shall describe the regular and periodic inspection procedures proposed to comply with § 71.51(c).

39 FR 2213

§ 71.25 Additional information.

The Commission may at any time require further information in order to enable it to determine whether a license, certificate of compliance, or other approval should be granted, denied, modified, suspended, or revoked.

Subpart C—Package Standards

31 FR 9941

§ 71.31 General standards for all packaging.

(a) Packaging shall be of such materials and construction that there will be no significant chemical, galvanic, or other reaction among the packaging components, or between the packaging components and the package contents.

(b) Packaging shall be equipped with a positive closure which will prevent inadvertent opening.

(c) Lifting devices:

(1) If there is a system of lifting devices which is a structural part of the package, the system shall be capable of supporting three times the weight of the loaded package without generating stress in any material of the packaging in excess of its yield strength.

(2) If there is a system of lifting

*Redesignated by FR 10437.

**Amended 37 FR 3985.

**Effective date of this amendment.

devices which is a structural part only of the lid, the system shall be capable of supporting three times the weight of the lid and any attachments without generating stress in any material of the lid in excess of its yield strength.

(3) If there is a structural part of the package which could be employed to lift the package and which does not comply with subparagraph (1) of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

(4) Each lifting device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the containment or shielding properties of the package.

(d) Tie-down devices:

(1) If there is a system of tie-down devices which is a structural part of the package, the system shall be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.

(2) If there is a structural part of the package which could be employed to tie the package down and which does not comply with subparagraph (1) of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

(3) Each tie-down device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this subpart.

31 FR 9941

§ 71.32 Structural standards for type B and large quantity packaging.

38 FR 10437

Packaging used to ship a type B or a large quantity of radioactive material, as defined in § 71.4 (q) and (f), shall be designed and constructed in accordance with the structural standards of this section.

31 FR 9941

Standards different from those specified in this section may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

(a) *Load resistance.* Regarded as a simple beam supported at its ends along any major axis, packaging shall be capable of withstanding a static load, normal to and uniformly distributed along its length, equal to 5 times its fully loaded weight, without generating stress in any material of the packaging in excess of its yield strength.

(b) *External pressure.* Packaging shall be adequate to assure that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 pounds per square inch gauge.

§ 71.33 Criticality standards for fissile material packages.

31 FR 9941

(a) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that water leaks into the containment vessel, and:

(1) Water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents; and

(2) The containment vessel is fully reflected on all sides by water.

(b) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that any contents of the package which are liquid during normal transport leak out of the containment vessel, and that the fissile material is then:

(1) In the most reactive credible configuration consistent with the chemical and physical form of the material;

(2) Moderated by water outside of the containment vessel to the most reactive credible extent; and

(3) Fully reflected on all sides by water.

(c) The Commission may approve exceptions to the requirements of this section where the containment vessel incorporates special design features which would preclude leakage of liquids in spite of any single packaging error and appropriate measures are taken before each shipment to verify the leak tightness of each containment vessel.

§ 71.34 Evaluation of a single package.

(a) The effect of the transport environment on the safety of any single package of radioactive material shall be evaluated as follows:

(1) The ability of a package to withstand conditions likely to occur in normal transport shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the normal conditions of transport as specified in § 71.35; and

(2) The effect on a package of conditions likely to occur in an accident shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the hypothetical accident conditions as specified in § 71.36.

(b) Taking into account controls to be exercised by the shipper, the Commission may permit the shipment to be evaluated together with or without the transporting vehicle, for the purpose of one or more tests.

31 FR 9941

(c) Normal conditions of transport and hypothetical accident conditions different from those specified in § 71.35 and § 71.36 may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

§ 71.35 Standards for normal conditions of transport for a single package.

38 FR 10437

(a) A package used for the shipment of fissile material or more than a type A quantity of radioactive material, as defined in § 71.4(q), shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in appendix A of this part:

(1) There will be no release of radioactive material from the containment vessel;

(2) The effectiveness of the packaging will not be substantially reduced;

(3) There will be no mixture of gases or vapors in the package which could, through any credible increase of pressure or an explosion, significantly reduce the effectiveness of the package;

(4) Radioactive contamination of the liquid or gaseous primary coolant will not exceed 10^{-7} curies of activity of Group I radionuclides per milliliter, 5×10^{-6} curies of activity of Group II radionuclides per milliliter, 3×10^{-4} curies of activity of Group III and Group IV radionuclides per milliliter; and

(5) There will be no loss of coolant.

31 FR 9941

(b) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Appendix A of this part:

(1) The package will be subcritical;

(2) The geometric form of the package contents would not be substantially altered;

(3) There will be no leakage of water into the containment vessel. This requirement need not be met if, in the

evaluation of undamaged packages under § 71.38(a), § 71.39(a)(1), or § 71.40(a), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material; and

(4) There will be no substantial reduction in the effectiveness of the packaging, including:

(i) Reduction by more than 5 percent in the total effective volume of the packaging on which nuclear safety is assessed;

(ii) Reduction by more than 5 percent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging; or

(iii) Occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a 4-inch cube.

31 FR 9941

(c) A package used for the shipment of more than a type A quantity of radioactive material as defined in § 71.4(q), shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in appendix A of this part, the containment vessel would not be vented directly to the atmosphere.

38 FR 10437

§ 71.36 Standards for hypothetical accident conditions for a single package.

(a) A package used for the shipment of more than a type A quantity of radioactive material, as defined in § 71.4(q), shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in appendix B of this part as the free drop, puncture, thermal, and water immersion conditions in the sequence listed in appendix B, it will meet the following conditions:

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(1) The reduction of shielding would not be sufficient to increase the external radiation dose rate to more than 1,000 millirems per hour at 3 feet from the external surface of the package.

(2) No radioactive material would be released from the package except for gases and contaminated coolant containing total radioactivity exceeding neither:

(i) 0.1 percent of the total radioactivity of the package contents; nor

(ii) 0.01 curie of Group I radionuclides, 0.5 curie of Group II radionuclides, 10 curies of Group III radionuclides, 10 curies of Group IV radionuclides, and 1,000 curies of inert gases irrespective of transport group.

A package need not satisfy the requirements of this paragraph if it contains only low specific activity materials, as defined in § 71.4(g), and is transported on a motor vehicle, railroad car, aircraft, inland water craft, or hold or deck of a seagoing vessel assigned for the sole use of the licensee.

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(b) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents;

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and

(3) There is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

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§ 71.37 Evaluation of an array of packages of fissile material.

(a) The effect of the transport environment on the nuclear safety of an array of packages of fissile material shall be evaluated by subjecting a sample package or a scale model, by test or other assessment, to the hypothetical accident conditions specified in § 71.38, § 71.39, or § 71.40 for the proposed fissile class, and by assuming that each package in the array is damaged to the same extent as the sample package or scale model. In this case of a Fissile Class III shipment, the Commission may, taking into account controls to be exercised by the shipper, permit the shipment to be evaluated as a whole rather than as individual packages, and either with or without the transporting vehicle, for the purpose of one or more tests.

(b) In determining whether the standards of §§ 71.38(b), 71.39(a)(2), and 71.40(b) are satisfied, it shall be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together; and

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

§ 71.38 Specific standards for a Fissile Class I package.

A Fissile Class I package shall be so designed and constructed and its contents so limited that:

(a) Any number of such undamaged packages would be subcritical in any arrangement, and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered; and

(b) Two hundred fifty such packages would be subcritical in any arrangement, if each package were subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in § 71.37.

31 FR 9941

§ 71.39 Specific standards for a Fissile Class II package.

(a) A Fissile Class II package shall be so designed and constructed and its contents so limited, and the number of such packages which may be transported together so limited, that:

(1) Five times that number of such undamaged packages would be subcritical in any arrangement if closely reflected by water; and

(2) Twice that number of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in § 71.37.

(b) The transport index for each Fissile Class II package is calculated by dividing the number 50 by the number of

33 FR 17621

such Fissile Class II packages which may be transported together as determined under the limitations of paragraph (a) of this section. The calculated number shall be rounded up to the first decimal place.

§ 71.40 Specific standards for a Fissile Class III shipment.

A package for Fissile Class III shipment shall be so designed and constructed and its contents so limited, and the number of packages in a Fissile Class III shipment shall be so limited, that:

(a) The undamaged shipment would be subcritical with an identical shipment in contact with it and with the two shipments closely reflected on all sides by water; and

(b) The shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with the packages in the most reactive arrangement and with the most reactive degree of interspersed hydrogenous moderation which would be credible considering the controls to be exercised over the shipment. The condition of the package shall be assumed to be as described in § 71.37. Hypothetical accident conditions different from those specified, in this paragraph may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

31 FR 9941

§ 71.41 Previously constructed packages for irradiated solid nuclear fuel.

Notwithstanding any other provisions of this Subpart, a package, the use of which has been authorized by the Commission for the transport of irradiated solid nuclear fuel on or after September 23, 1961, and which has been completely constructed prior to January 1, 1967, shall be deemed to comply with the package standards of this subpart for that purpose.

§ 71.42 Special requirements for plutonium shipments after June 17, 1978.

39 FR 20960

(a) Notwithstanding the exemption in § 71.9, plutonium in excess of twenty (20) curies per package shall be shipped as a solid.

(b) Plutonium in excess of twenty (20) curies per package shall be packaged in a separate inner container placed within outer packaging that meets the requirements of Subpart C for packaging of material in normal form. The separate inner container shall not release plutonium when the entire package is subjected to the normal and accident test conditions specified in Appendices A and B. Solid plutonium in the following forms is exempt from the requirements of this paragraph:

(1) Reactor fuel elements;

(2) Metal or metal alloy; or

(3) Other plutonium bearing solids that the Commission determines should be exempt from the requirements of this section.

(c) Authority in licenses issued pursuant to this part for delivery of plutonium to a carrier for transport under conditions which do not meet the limitations of paragraphs (a) and (b) of this section shall expire on June 17, 1978.

Subpart D—Operating Procedures

§ 71.51 Establishment and maintenance of procedures.

The licensee shall establish and maintain:

(a) Operating procedures adequate to assure that the determinations and controls required by this chapter are accomplished;

37 FR 3985

(b) Procedures for opening and closing packages in which licensed material is transported to provide safety and to assure that, prior to delivery to a carrier for transport, each package is properly closed for transport; and

(c) Regular and periodic inspection procedures adequate to assure that the procedures required by paragraphs (a) and (b) of this section are followed.

§ 71.52 Assumptions as to unknown properties.

31 FR 9941

When the isotopic abundance, mass, concentration, degree of irradiation, degree of moderation, or other pertinent property of fissile material in any package is not known, the licensee shall package the fissile material as if the unknown properties have such credible values as will cause the maximum nuclear reactivity.

§ 71.53 Preliminary determinations.

(a) Prior to the first use of any packaging for the shipment of licensed materials, the licensee shall ascertain that there are no cracks, pinholes, uncontrolled voids or other defects which could significantly reduce the effectiveness of the packaging.

(b) Prior to the first use of any packaging for the shipment of licensed materials, where the maximum normal operating pressure will exceed 5 pounds per square inch gauge, the licensee shall test the containment vessel to assure that it will not leak at an internal pressure 50 percent higher than the maximum normal operating pressure.

(c) Packaging shall be conspicuously and durably marked with its model number. Prior to applying the model number, the licensee shall determine that the packaging has been fabricated in accordance with the design approved by the Commission.

§ 71.54 Routine determinations.

31 FR 9941

Prior to each use of a package for shipment of licensed material the licensee shall ascertain that the package with its contents satisfies the applicable requirements of Subpart C of this part and of the license, including determinations that:

(a) The packaging has not been significantly damaged;

(b) Any moderators and nonfissile neutron absorbers, if required, are present and are as authorized by the Commission;

(c) The closure of the package and any sealing gaskets are present and are free from defects;

(d) Any valve through which primary coolant can flow is protected against tampering;

(e) The internal gauge pressure of the package will not exceed, during the anticipated period of transport, the maximum normal operating pressure;

(f) Contamination of the primary coolant will not exceed, during the anticipated period of transport, the limits specified in § 71.35(a) (4).

The provisions of this section shall not be applicable for packages authorized in the general licenses granted by § 71.6. In such cases the licensee shall ascertain that the contents of the package are as authorized in the general license.

§ 71.55 Opening instructions.

37 FR 3985

Prior to delivery of a package to a carrier for transport, the licensee shall assure that any special instruction needed to safely open the package are sent to or have been made available to the consignee.

§ 71.61 Reports.

31 FR 9941

The licensee shall report to the Director of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, within 30 days any instance in which

there is substantial reduction in the effectiveness of any authorized packaging during use.

38 FR 10437

§ 71.62 Records.

(a) The licensee shall maintain for a period of 2 years after its generation a record of each shipment of fissile material or of more than a type A quantity of radioactive material as defined in § 71.4(q), in a single package, showing, where applicable:

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(1) Identification of the packaging by model number;
(2) Details of any significant defects in the packaging, with the means employed to repair the defects and prevent their recurrence;
(3) Volume and identification of coolant;
(4) Type and quantity of licensed material in each package, and the total quantity in each shipment;
(5) For each item of irradiated fissile material;
(i) Identification by model number;
(ii) Irradiation and decay history to the extent appropriate to demonstrate that its nuclear and thermal characteristics comply with license conditions;
(iii) Any abnormal or unusual condition relevant to radiation safety.
(6) Date of the shipment;
(7) For Fissile Class III, any special controls exercised;
(8) Name and address of the transferee;
(9) Address to which the shipment was made; and
(10) Results of the determinations required by §§ 71.53 and 71.54.
(b) The licensee shall make available to the Commission for inspection, upon reasonable notice, all records required by this part.

§ 71.63 Inspection and tests.

(a) The licensee shall permit the Commission at all reasonable times to inspect the licensed material, packaging, and premises and facilities in which the licensed material or packaging are used, produced, tested, stored or shipped.
(b) The licensee shall perform and permit the Commission to perform, such tests as the Commission deems necessary or appropriate for the administration of the regulations in this chapter.

40 FR 8774

§ 71.64 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction may be punished by fine or imprisonment or both, as provided by law.

40 FR 8774

APPENDICES

APPENDIX A—NORMAL CONDITIONS OF TRANSPORT

Each of the following normal conditions of transport is to be applied separately to determine its effect on a package.

1. *Heat*—Direct sunlight at an ambient temperature of 130° F. in still air.
2. *Cold*—An ambient temperature of −40° F. in still air and shade.
3. *Pressure*—Atmospheric pressure of 0.5 times standard atmospheric pressure.
4. *Vibration*—Vibration normally incident to transport.
5. *Water Spray*—A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period 30 minutes.

6. *Free Drop*—Between 1-1/2 and 2-1/2 hours after the conclusion of the water spray test, a free drop through the distance specified below onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

FREE FALL DISTANCE

Package weight (pounds)	*Distance (feet)*
Less than 10,000	4
10,000 to 20,000	3
20,000 to 30,000	2
More than 30,000	1

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7. *Corner Drop*—A free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 1 foot onto a flat essentially unyielding horizontal surface. This test applies only to packages which are constructed primarily of wood or fiberboard, and do not exceed 110 pounds gross weight, and to all Fissile Class II packagings.
8. *Penetration*—Impact of the hemispherical end of a vertical steel cylinder 1-1/4 inches in diameter and weighing 13 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder shall be perpendicular to the package surface.

9. *Compression*—For packages not exceeding 10,000 pounds in weight, a compressive load equal to either 5 times the weight of the package or 2 pounds per square inch multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported.

APPENDIX B—HYPOTHETICAL ACCIDENT CONDITIONS

The following hypothetical accident conditions are to be applied sequentially, in the order indicated, to determine their cumulative effect on a package or array of packages.

1. *Free Drop*—A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

2. *Puncture*—A free drop through a distance of 40 inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.

3. *Thermal*—Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1,475° F. for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.

4. *Water Immersion* (fissile material packages only)—Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.

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APPENDIX C—TRANSPORT GROUPING OF RADIONUCLIDES

Element*	Radionuclide***	Group
Actinium (89)	Ac 227	I
	Ac 228	I
Americum (96)	Am 241	I
	Am 243	I
Antimony (51)	Sb 122	IV
	Sb 124	III
	Sb 125	III
Argon (18)	Ar-37	VI
	Ar-41	II
	Ar-41 (uncompressed)**	V
Arsenic (33)	As 73	IV
	As 74	IV
	As 76	IV
	As 77	IV
Astatine (85)	At 211	III
Barium (56)	Ba 131	IV
	Ba-133	II
	Ba 140	III
Berkelium (97)	Bk 249	I
Beryllium (4)	Be 7	IV
Bismuth (83)	Bi 206	IV
	Bi 207	III
	Bi 210	II
	Bi 212	III
Bromine (35)	Br 82	IV
Cadmium (48)	Cd 109	IV
	Cd 115 m	III
	Cd 115	IV
Calcium (20)	Ca 45	IV
	Ca 47	IV
Californium (98)	Cf 249	I
	Cf 250	I
	Cf 252	I
Carbon (6)	C 14	IV
Cerium (58)	Ce 141	IV
	Ce 143	IV
	Ce 144	III
Cesium (55)	Cs 131	IV
	Cs 134 m	III
	Cs 134	III
	Cs 135	IV
	Cs 136	IV
	Cs 137	III
Chlorine (17)	Cl 36	III
	Cl 138	IV
Chromium (24)	Cr 51	IV
Cobalt (27)	Co 56	III
	Co 57	IV
	Co 58 m	IV
	Co 58	IV
	Co 60	III
Copper (29)	Cu 64	IV
Curium (96)	Cm 242	I
	Cm 243	I
	Cm 244	I
	Cm 245	I
	Cm 246	I
Dysprosium (66)	Dy 154	III
	Dy 165	IV
	Dy 166	IV
Erbium (68)	Er 169	IV
	Er 171	IV
Europium (63)	Eu 150	III
	Eu 152 m	IV
	Eu 152	III
	Eu 154	II
	Eu 155	IV
Fluorine (9)	F 18	IV
Gadolinium (64)	Gd 153	IV
	Gd 159	IV
Gallium (31)	Ga 67	III
	Ga 72	IV
Germanium (32)	Ge 71	IV
Gold (79)	Au 193	III
	Au 194	III
	Au 195	III
	Au 196	IV
	Au 198	IV
	Au 199	IV
Hafnium (72)	Hf 181	IV
Holmium (67)	Ho 166	IV
Hydrogen (1)	H 3 (see tritium)	
Indium (49)	In 113 m	IV
	In 114 m	III
	In 115 m	IV
	In 115	IV
Iodine (53)	I 124	III
	I 125	III
	I 126	III
	I 129	III
	I 131	III
	I 132	IV
	I 133	III
	I 134	IV
	I 135	IV
Iridium (77)	Ir 190	IV
	Ir 192	III
	Ir 194	IV
Iron (26)	Fe 55	IV
	Fe 59	IV
Krypton (36)	Kr 85 m	III
	Kr 85 m (uncompressed)**	V
	Kr 85	III
	Kr 85 (uncompressed)**	VI
	Kr 87	II
	Kr 87 (uncompressed)**	V
Lanthanum (57)	La 140	IV
Lead (82)	Pb 203	IV
	Pb 210	II
	Pb 212	II
Lutecium (71)	Lu 172	III
	Lu 177	IV
Magnesium (12)	Mg 28	III
Manganese (25)	Mn 52	IV
	Mn 54	IV
	Mn 56	IV
Mercury (80)	Hg 197 m	IV
	Mn 56	IV
Mercury (80)	Hg 197 m	IV
	Hg 197	IV
	Hg 203	IV
Mixed fission products MFP		II
Molybdenum (42)	Mo 99	IV
Neodymium (60)	Nd 147	IV
	Nd 149	IV
Neptunium (93)	Np 237	I
	Np 239	I
Nickel (28)	Ni 56	III
	Ni 59	IV
	Ni 63	IV
	Ni 65	IV
Niobium (41)	Nb 93 m	IV
	Nb 95	IV
	Nb 97	IV
Osmium (76)	Os 185	IV
	Os 191 m	IV
	Os 191	IV
	Os 193	IV
Palladium (46)	Pd 103	IV
	Pd 109	IV
Phosphorus (15)	P 32	IV
Platinum (78)	Pt 191	IV
	Pt 193	IV
	Pt 193 m	IV
	Pt 197 m	IV
	Pt 197	IV
Plutonium (94)	Pu 238 (F)	I
	Pu 239 (F)	I

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See footnotes at end of table.

APPENDIX C—TRANSPORT GROUPING OF RADIONUCLIDES—Continued

Element*	Radionuclides***	Group
	Pu 240	I
	Pu 241 (F)	I
	Pu 242	I
Polonium (84)	Po 210	I
Potassium (19)	K 42	IV
	K 43	III
Praseodymium (59)	Pr 142	IV
	Pr 143	IV
Promethium (61)	Pm 147	IV
	Pm 149	IV
Protactinium (91)	Pa 230	I
	Pa 231	I
	Pa 233	II
Radium (88)	Ra 223	II
	Ra 224	II
	Ra 236	I
	Ra 228	I
Radon (86)	Rn 220	IV
	Rn 222	II
Rhenium (75)	Re 183	IV
	Re 186	IV
	Re 187	IV
	Re 188	IV
	Re Natural	IV
Rhodium (45)	Rh 103 m	IV
	Rh 105	IV
Rubidium (37)	Rb 86	IV
	Rb 87	IV
	Rb Natural	IV
Ruthenium (44)	Ru 97	IV
	Ru 103	IV
	Ru 105	IV
	Ru 106	III
Samarium (62)	Sm 145	III
	Sm 147	III
	Sm 151	IV
	Sm 153	IV
Scandium (21)	Sc 46	III
	Sc 47	IV
	Sc 48	IV
Selenium (34)	Se 75	IV
Silicon (14)	Si 31	IV
Silver (47)el1	Ag 105	IV
	Ag 110 m	III
	Ag 111	IV
Sodium (11)	Na 22	III
	Na 24	IV
Strontium (38)	Sr 85 m	IV
	Sr 85	IV
	Sr 89	III
	Sr 90	II
	Sr 91	III
	Sr 92	IV
Sulphur (16)	S 35	IV
Tantalum (73)	Ta 182	III
Technetium (43)	Te 96 m	IV
	Te 96	IV
	Te 97 m	IV
	Te 97	IV
	Te 99 m	IV
	Te 99	IV
Tellurium (52)	Te 125 m	IV
	Te 127 m	IV
	Te 127	IV
	Te 129 m	III
	Te 129	IV
	Te 131 m	III
	Te 132	IV
Terbium (65)	Tb 160	III
Thallium (81)	Tl 200	IV
	Tl 201	IV
	Tl 202	IV
	Tl 204	III
Thorium (90)	Th 227	II
	Th 228	I
	Th 230	I
	Th 231	I
	Th 232	III
	Th 234	II
	Th Natural	III
Thulium (69)	Tm 168	III
	Tm 170	III
	Tm 171	IV
Tin (50)	Sn 113	IV
	Sn 117 m	III
	Sn 121	III
	Sn 125	IV
Tritium (1)	H 3	IV
	H 3 (as a gas, as luminous paint, or adsorbed on solid material)	VII
Tungsten (74)	W 181	IV
	W 185	IV
	W 187	IV
Uranium (92)	U 230	II
	U 232	I
	U 233 (F)	II
	U 234	II
	U 235 (F)	III
	U 236	II
	U 238	III
	U Natural	III
	U Enriched (F)	III
	U Depleted	III
Vanadium (23)	V 48	IV
	V 49	III
Xenon (54)	Xe 125	III
	Xe 131 m	III
	Xe 131 m (uncompressed)**	V
	Xe 133	III
	Xe 133 (uncompressed)**	VI
	Xe 135	II
	Xe 135 (uncompressed)**	V
Ytterbium (70)	Yb 175	IV
Yttrium (39)	Y 88	III
	Y 90	IV
	Y 91 m	III
	Y 91	III
	Y 92	IV
	Y 93	IV
Zinc (30)	Zn 65	IV
	Zn 69 m	IV
	Zn 69	IV
Zirconium (40)	Zr 93	IV
	Zr 95	III
	Zr 97	IV

[31 FR 9941] [33 FR 17621]

*Atomic number shown in parentheses.
**Uncompressed means at a pressure not exceeding one atmosphere.
***Atomic weight shown after the radionuclide symbol.
m—Metastable state.
(F) Fissile material.

APPENDIX D—TESTS FOR SPECIAL FORM LICENSED MATERIAL

1. *Free Drop*—A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage.

2. *Percussion*—Impact of the flat circular end of a 1 inch diameter steel rod weighing 3 pounds, dropped through a distance of 40 inches. The capsule or material shall be placed on a sheet of lead, of hardness numberr 3.5 to 4.5 on the Vickers scale, and not more than 1 inch thick, supported by a smooth essentially unyielding surface.

3. *Heating*—Heating in air to a temperature of 1,475° F. and remaining at that temperature for a period of 10 minutes.

4. *Immersion*—Immersion for 24 hours in water at room temperature. The water shall be at pH 6–pH 8, with a maximum conductivity of 10 micrombos per centimeter.

[31 FR 9941] [33 FR 17621]

[31 FR 9941]

The record keeping and reporting requirements contained in this part have been approved by the Bureau of the Budget in accordance with the Federal Reports Act of 1942.

See footnotes at end of table.

APPENDIX D-2

DEPARTMENT OF TRANSPORTATION

49 CFR 173.393. General Packaging and Shipping Requirements

§ 173.393 General packaging and shipment requirements.

(a) Unless otherwise specified, all shipments of radioactive materials must meet all requirements of this section, and must be packaged as prescribed in §§ 173.391 through 173.396.

(b) The outside of each package must incorporate a feature such as a seal, which is not readily breakable and which, while intact, will be evidence that the package has not been illicitly opened.

(c) The smallest outside dimension of any package must be 4 inches or greater.

(d) Each radioactive material must be packaged in a packaging which has been designed to maintain shielding efficiency and leak tightness, so that, under conditions normally incident to transportation, there will be no release of radioactive material. If necessary, additional suitable inside packaging must be used. Each package must be capable of meeting the standards in §§ 173.398(b) and 173.24.

. Specification containers listed as authorized for radioactive materials shipments may be assumed to meet those standards, provided the packages do not exceed the gross weight limits prescribed for those containers in Part 178 of this chapter.

(1) Internal bracing or cushioning, where used, must be adequate to assure that, under the conditions normally incident to transportation, the distance from the inner container or radioactive material to the outside wall of the package remains within the limits for which the package design was based, and the radiation dose rate external to the package does not exceed the transport index number shown on the label. Inner shield closures must be positively secured to prevent loss of the contents.

(e) The packaging must be designed, constructed, and loaded so that during transport:

(1) The heat generated within the package because of the radioactive materials present will not, at any time during transportation, affect the efficiency of the package under the conditions normally incident to transportation, and

(2) The temperature of the accessible external surfaces of the package will not exceed 122° F. in the shade when fully loaded, assuming still air at ambient temperature. If the package is transported in a transport vehicle consigned for the sole use of the consignor, the maximum accessible external surface temperature shall be 180° F.

(f) Pyrophoric materials, in addition to the packaging prescribed in this subpart, must also meet the packaging requirements of § 173.134 or § 173.154. Pyrophoric radioactive liquids may not be shipped by air.

(g) Liquid radioactive material in Type A quantities must be packaged in or within a leak-resistant and corrosion-resistant inner containment vessel. In addition:

(1) The packaging must be adequate to prevent loss or dispersal of the radioactive contents from the inner containment vessel if the package were subjected to the 9 meter (30-foot) drop test prescribed in § 173.393(c) (2) (i); and either

(2) Enough absorbent material must be provided to absorb at least twice the volume of radioactive liquid contents. The absorbent material may be located outside the radiation shield only if it can be shown that if the radioactive liquid contents were taken up by the absorbent material the resultant dose rate at the surface of the package would not exceed 1,000 millirem per hour; or

(3) A secondary leak-resistant and corrosion-resistant containment vessel must be provided to retain the radioactive contents under the normal conditions of transport as prescribed in § 173.398(b), assuming the failure of the inner primary containment vessel.

(h) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(i) Except for shipments described in paragraph (j) of this section, all radioactive materials must be packaged in suitable packaging (shielded, if necessary) so that at any time during the normal conditions incident to transportation the radiation dose rate does not exceed 200 millirem per hour at any point on the external surface of the package, and the transport index does not exceed 10.

(j) Packages for which the radiation dose rate exceeds the limits specified in paragraph (i) of this section, but does not exceed at any time during transportation any of the limits specified in paragraphs (j) (1) through (4) of this section may be transported in a transport vehicle which has been consigned as exclusive use (except aircraft). Specific instructions for maintenance of the exclusive use (sole use) shipment controls must be provided by the shipper to the carrier. Such instructions must be included with the shipping paper information:

(1) 1,000 millirem per hour at 3 feet from the external surface of the package (closed transport vehicle only);

(2) 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only);

(3) Ten millirem per hour at any point 2 meters (six feet) from the vertical planes projected by the outer lateral surface of the car or vehicle; or if the load

is transported in an open transport vehicle, at any point 2 meters (six feet) from the vertical planes projected from the outer edges of the vehicle.

(4) 2 millirem per hour in any normally occupied position in the car or vehicle, except that this provision does not apply to private motor carriers.

(k) [Reserved]

(l) Packages consigned for export are also subject to the regulations of the foreign governments involved in the shipment. See §§ 173.8, 173.9, and 173.393b. (The regulations of the International Atomic Energy Agency (IAEA) are used by most foreign governments.)

(m) Prior to the first shipment of any package, the shipper shall determine by examination or appropriate test that:

(1) The packaging meets the specified quality of design and construction; and

(2) The effectiveness of the shielding and containment, and, where necessary, the heat transfer characteristics of the package are within the limits applicable to or specified for the package design.

(n) Prior to each shipment of any package, the shipper shall insure by examination or appropriate test that:

(1) The package is proper for the contents to be shipped;

(2) The packaging is in unimpaired physical condition except for superficial marks;

(3) Each closure device of the packaging, including any required gasket, is properly installed and secured and free of defects;

(4) For a fissile material, any moderator and neutron absorber, if required, is present in proper condition;

(5) Any special instructions for filling, closing, and preparation of the package for shipment have been followed;

(6) Each closure, valve, and any other opening of the containment system through which the radioactive content might escape is properly closed and sealed;

(7) Each package containing liquid in excess of a Type A quantity and destined for air shipment is tested to demonstrate that it is leak tight under an ambient atmospheric pressure differential of at least 0.5 atmosphere (absolute) (7.3 p.s.i.a. or 0.5 kg./cm.^{2}); the test may be conducted on the entire containment system or on any receptacle or vessel within the containment system, as appropriate to determine compliance with the requirement;

(8) If the maximum normal operating pressure of a package is likely to exceed 0.35 kg./cm.^{2} (gage), the internal pressure of the containment system will not exceed the design pressure during transportation; and

(9) External radiation and contamination levels are within the allowable limits.

(o) No person may offer for transportation a package of radioactive materials until the temperature of the packaging system has reached equilibrium (see also paragraph (e) of this section) unless, for the specific contents, he has ascertained that the maximum applicable surface temperature limits cannot be exceeded.

APPENDIX D-3

DEPARTMENT OF TRANSPORTATION

49 CFR 173.391. Small Quantities of Radioactive Materials and Radioactive Devices

§ 173.391 Small quantities of radioactive materials and radioactive devices.

(a) Radioactive materials in normal form not exceeding 0.01 millicurie of Group I radionuclides; 0.1 millicurie of Group II radionuclides; 1 millicurie of Groups III, IV, V, or VI radionuclides; 25 curies of Group VII radionuclides; tritium oxide in aqueous solution with a concentration not exceeding 0.5 millicuries per milliliter and with a total activity per package of not more than 3 curies; or 1 millicurie of radioactive material in special form; and not containing more than 15 grams of uranium-235 are exempt from specification packaging, marking, and labeling, and are exempt from the provisions of § 173.393, if the following conditions are met:

(1) The materials are packaged in strong tight packages such that there will be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The package must be such that the radiation dose rate at any point on the external surface of the package does not exceed 0.5 millirem per hour.

(3) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(4) The outside of the inner container must bear the marking "Radioactive."

(b) Manufactured articles such as instruments, clocks, electronic tubes or apparatus, or other similar devices, having radioactive materials (other than liquids) in a nondispersible form as a component part, are exempt from specification packaging, marking, and labeling, and are exempt from the provisions of § 173.393, if the following conditions are met:

NOTE 1: For radioactive gases, the requirement for the radioactive material to be in a nondispersible form does not apply.

(1) Radioactive materials are securely contained within the devices, or are securely packaged in strong, tight packages, so that there will be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The radiation dose rate at four inches from any unpackaged device does not exceed 10 millirem per hour.

(3) The radiation dose rate at any point on the external surface of the outside of the package may not exceed 0.5 millirem per hour. However, for exclusive use shipments only, the radiation at the external surface of the package or the item may exceed 0.5 millirem per hour, but must not exceed 2 millirem per hour.

(4) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(5) The total radioactivity content of a package containing radioactive devices must not exceed the quantities shown in the following table:

Transport group	Quantity in curies	
	Per device	Per package
I	0.0001	0.001
II	0.001	0.05
III	0.01	3
IV	0.05	3
V or VI	1	1
VII	25	200
Special form	0.05	20

(6) No package may contain more than 15 grams of fissile material.

(c) A manufactured article, other than reactor fuel elements, in which the only radioactive material is metallic natural or depleted uranium or natural thorium or alloys thereof, is exempt from specification packaging, marking, and labeling, and is exempt from the provisions of § 173.393, if the following conditions are met:

(c) Manufactured articles, other than reactor fuel elements, in which the only radioactive material is natural or depleted uranium, are exempt from specification packaging, marking, and labeling and are exempt from the provisions of § 173.393, if the following conditions are met:

(1) The radiation dose rate at any point on the external surface of the outside container does not exceed 0.5 millirem per hour;

(2) There must be no significant radioactive surface contamination on the exterior of the package. To determine whether "significant," the standard in § 173.397 must be used.

(3) The total radioactivity content of each article must not exceed 3 curies.

(4) The outer surface of the uranium or thorium is enclosed in a non-radioactive, sealed, metallic sheath.

(d) Shipments made under this section for transportation by motor carriers are exempt from Part 177, except § 177.817, of this chapter.

APPENDIX D-4

NUCLEAR REGULATORY COMMISSION

10 CFR 73.30-36. Physical Protection of Special Nuclear Material in Transit

barbed topping described in paragraph (f)(1) of this section of a height of not less than 8 feet.

(3) Ceilings and floors constructed to offer resistance to penetration equivalent to that of building walls described in paragraph (f)(2) of this section.

(g) "Protected area" means an area encompassed by physical barriers and to which access is controlled.

(h) "Vital area" means any area which contains vital equipment within a structure, the walls, roof, and floor of which constitute physical barriers of construction at least as substantial as walls as described in paragraph (f)(2) of this section.

(i) "Vital equipment" means any equipment, system, device, or material, the failure, destruction, or release of which could directly or indirectly endanger the public health and safety by exposure to radiation. Equipment or systems which would be required to function to protect public health and safety following such failure, destruction, or release are also considered to be vital.

(j) "Material access area" means any location which contains special nuclear material, within a vault or a building, the roof, walls, and floor of which each constitute a physical barrier.

(k) "Isolation zone" means any area, clear of all objects which could conceal or shield an individual, adjacent to a physical barrier, which is monitored to detect the presence of individuals or vehicles within that area.

(l) "Intrusion alarm" means a tamper indicating electrical, electromechanical, electro-optical, electronic or similar device which will detect intrusion by an individual into a building, protected area, vital area, or material access area, and alert guards or watchmen by means of actuated visible and audible signals.

(m) "Lock" in the case of vaults or vault type rooms means a three-position, manipulation resistant, dial type, built-in combination lock or combination padlock and in the case of fences, walls, and buildings means an integral door lock or padlock which provides protection equivalent to a six-tumbler cylinder lock. "Lock" in the case of a vault or vault type room also means any manipulation resistant, electromechanical device which provides the same function as a built-in combination lock or combination padlock, which can be operated remotely or by the "reading" or insertion of information, which can be uniquely characterized, and which allows operation of the device. "Locked" means protected by an operable lock.

(n) "Vault" means a burglar-resistant windowless enclosure with walls, floor and roof of: (1) Steel at least one-half inch thick, (2) reinforced concrete or stone at least 8 inches thick, (3) non-reinforced concrete or stone at least 12 inches thick, or (4) monolithic floor or roof construction of equivalent resistance to entry, with a built-in lock in a steel door at least 1 inch thick, exclusive of the locking mechanism.

(o) "Vault-type room" means a room with one or more doors, all capable of being locked, protected by an intrusion alarm which creates an alarm upon the entry of a person anywhere into the room and upon exit from the room or upon movement of an individual within the room.

(p) "Industrial sabotage" means any deliberate act directed against a plant in which an activity licensed pursuant to the regulations in this chapter is conducted, or to any component of such a plant, which could directly or indirectly endanger the public health and safety by exposure to radiation, other than such acts by an enemy of the United States, whether foreign government or other person.

(q) "ERDA" means the Energy Research and Development Administration or its duly authorized representatives.

§ 73.3 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized as binding upon the Commission.

§ 73.4 Communications.

Except where otherwise specified, all communications and reports concerning the regulations in this part should be addressed to the Director of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, or may be delivered in person at the Commission's offices at 1717 H Street, NW., Washington, D.C.; at 7920 Norfolk Avenue, Bethesda, Maryland.

§ 73.5 Specific exemptions.

The Commission may, upon application of any interested person or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not endanger life or property or the common defense and security, and are otherwise in the public interest.

§ 73.6 Exemptions for certain quantities and kinds of special nuclear material.

A licensee is exempt from the requirements of §§ 73.30 through 73.36 and of §§ 73.60 and 73.70 of this part, with respect to the following special nuclear material:

(a) Uranium-235 contained in uranium enriched to less than 20 percent in the U-235 isotope;

(b) Special nuclear material which is not readily separable from other radioactive material and which has a total external radiation dose rate in excess of 100 rems per hour at a distance of 3 feet from any accessible surface without intervening shielding; and

(c) Special nuclear material in a quantity not exceeding 350 grams of uranium-235, uranium-233, plutonium, or a combination thereof, possessed in any analytical, research, quality control metallurgical or electronic laboratory.

Physical Protection of Special Nuclear Material in Transit

§ 73.30 General requirements.

(a) Except as specified in § 73.36(a) or as otherwise authorized pursuant to § 73.30(f), each licensee who transports or who delivers to a carrier for transport either uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233, or plutonium, or any combination of these materials, which is 5,000 grams or more computed by the formula, grams = (grams contained U-235) + 2.5 (grams U-233 + grams plutonium), shall make arrangements to assure that such special nuclear material will, if a common or contract carrier is used, be transported under the established procedures of a carrier which provides a system for the physical protection of valuable material in transit and requires an exchange of hand-to-hand receipts at origin and destination and at all points enroute where there is a transfer of custody.

(b) Transit times of shipments other than those specified in § 73.1(b)(3) shall be minimized and routes shall be selected to avoid areas of natural disaster or civil disorders. Such shipments shall be preplanned to assure that deliveries occur at a time when the receiver at the final delivery point is present to accept receipt of shipment.

(c) Special nuclear material shall be shipped in containers which are sealed by a tamper indicating type seals. The container shall also be locked if it is not in another container or vehicle which is locked. If inspection of the container or vehicle is not required by State or local authorities before final destination, the outermost container or vehicle shall also be sealed by tamper indicating type seals. No container weighing 500 pounds or less shall be shipped in open trucks, railroad flat cars or box cars and ships. This paragraph does not apply to shipments of quantities specified in § 73.1(b)(3).

(d) When guards are used pursuant to §§ 73.31(c)(1), 73.31(c)(2), 73.33 and 73.35, the licensee shall not permit an individual to act as a guard unless there is documentation that the individual has been qualified by demonstrating an understanding of his duties and responsibilities. The licensee or his agent shall have documentation that guards have been requalified annually.

(e) By January 7, 1974, each licensee shall submit a plan outlining the procedures that will be used to meet the requirements of §§ 73.30 through 73.36 and 73.70(g) including a plan for the selection, qualification, and training of armed escorts, or the specification and design of a specially designed truck or trailer as appropriate. This plan shall be followed by the licensee after March 6, 1974.

(f) A licensee or applicant for a license may apply to the Commission for approval of proposed procedures for transport of special nuclear material in a manner not otherwise authorized by the regulations of this part. Such application shall include a description and quantity of the special nuclear material involved, the origin and destination, the

carriers to be used, the expected time in transit, the number of transfer points, the communications to be used, the vehicle visual identification, and the cargo security and surveillance measures to be used.

(g) Paragraphs (b), (c), (d), and (f) of this section are effective March 6, 1974.

§ 73.31 Shipment by road.

(a) All shipments by road shall be made without any scheduled intermediate stops to transfer special nuclear material or other cargo between the facility from which it is shipped and the facility of the receiver.

(b) All motor vehicles used to transport special nuclear material shall be equipped with a radiotelephone which can communicate with a licensee or his agent. The licensee or agent with whom communications shall be maintained for different segments of the shipment shall be predesignated before a shipment is made. Calls to such licensee or agent shall be made at least every 2 hours when radiotelephone or conventional telephone coverage along the route is available to relay position and projected route. Call frequency may extend up to 5 hours when radiotelephone or conventional telephone coverage is not available along the preplanned route, at which time a conventional telephone call shall be made. In the event no call is received in accordance with these requirements, the licensee or his agent shall immediately notify an appropriate law enforcement authority and the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of this part.

(c) A shipment shall be accompanied by at least two people in the vehicle containing the shipment, which may be two drivers or one driver and an authorized individual. The vehicle containing the shipment shall be under continuous visual surveillance, or one of the drivers or authorized individuals shall be in the cab of the vehicle, awake, and not in a sleeper berth. The shipment shall be further protected by one of the following methods:

(1) An armed escort consisting of at least two guards shall accompany the shipment in a separate escort vehicle. Escorts shall maintain continuous vigilance for the presence of conditions or situations which might threaten the security of the shipment, take such action as circumstances might require to avoid interference with continuous safe passage of the cargo vehicle, provide assistance to, or summon aid for crew of cargo vehicles in case of emergency, check seals and locks at each stop where time permits, and observe the cargo vehicle and adjacent areas during stops or layovers. Continuous radio communication capability shall be provided between the cargo vehicle and the escort vehicle. Escort vehicles shall also be equipped with a radiotelephone. The licensee may use his own employees as armed escorts or he may use an agent. Only the driver is required in the vehicle containing special nuclear material for shipments involving an average of less than an hour in transportation, if communication is maintained during the course of the shipment with the licensee or agent monitoring the shipment.

(2) The shipment shall be made in a specially designed truck or trailer which reduces the vulnerability to diversion. Design features of the truck or trailer shall permit immobilization of the van and provide barriers or deterrents to physical penetration of the cargo compartment unless armed guards are also used in which case immobilization of the vehicle is not required.

(d) Transfers to and from other modes of transportation shall be in accordance with § 73.35.

(e) Vehicles shall be marked on top with identifying letters or numbers which will permit identification of the vehicle under daylight conditions from the air in clear weather at 1,000 feet above ground level. The same code of letters and numbers as those used on the top shall also be marked on the sides and rear of the vehicle to permit identification from the ground.

(f) This section is effective March 6, 1974.

§ 73.32 Shipment by air.

(a) Except as specifically approved by the Nuclear Regulatory Commission, no shipment of special nuclear material shall be made in passenger aircraft in excess of (1) 20 grams or 20 curies, whichever is less, of plutonium or uranium-233, or (2) 350 grams of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope).

(b) In shipments on cargo aircraft of either uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233 or plutonium, or any combination of these materials which is 5,000 grams or more computed by the formula, grams = (grams contained U-235) + 2.5(grams U-233 + grams plutonium), transfers shall be in accordance with § 73.35. Transfers shall be minimized.

(c) Export shipments shall be escorted by an unarmed authorized individual, who may be a crew member, from the last terminal in the United States until the shipment is unloaded at a foreign terminal. He shall perform monitoring duties at foreign terminals as described in § 73.35.

(d) Paragraph (c) of this section is effective March 6, 1974.

§ 73.33 Shipment by rail.

(a) A shipment by rail shall be escorted by two guards, in the shipment car or an escort car of the train, who shall keep the shipment cars under observation and who shall detrain at stops when practicable and time permits to guard the shipment cars under observation, and check car or container locks and seals. Radiotelephone communication shall be maintained with a licensee or his agent to relay position every 2 hours or less, and at scheduled stops in the event that radiotelephone coverage was not available in the last 5 hours before the stop. The licensee or agent with whom communications shall be maintained for different segments of the shipment shall be predesignated before a shipment is made. In the event no call is received in accordance with these requirements, the licensee or his agent shall immediately notify an appropriate law enforcement authority and the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of this part.

(b) Transfers shall be in accordance with § 73.35.

(c) This section is effective March 6, 1974.

§ 73.34 Shipment by sea.

(a) Shipments shall be made on vessels making the minimum ports of call. Transfers to and from other modes of transportation shall be in accordance with § 73.35. There shall be no scheduled transfers to other ships. At domestic ports of call where other cargo is transferred, the shipments shall be protected in accordance with § 73.35(a).

(b) The shipment shall be placed in a secure compartment which is locked and sealed. Locks and seals shall be periodically inspected in transit, if accessible, by an escort or crew member.

(c) Export shipments shall be escorted by an unarmed authorized individual, who may be a crew member, from the last port in the United States until the shipment is unloaded at a foreign port. He shall perform monitoring duties at foreign ports as described in § 73.35.

(d) Ship-to-shore communications shall be available, and a ship-to-shore contact shall be made every twenty-four hours to relay position information, and the status of the shipment, which shall be determined by a daily inspection where possible. This information shall be sent, as often as it is available, to the licensee or his agent who makes the arrangements for the protection of the shipment.

(e) This section is effective March 6, 1974.

§ 73.35 Transfer of special nuclear material.

All transfers shall be monitored by a guard. An alternate guard shall be designated at all transfer points to substitute, if necessary. Monitoring of special nuclear material transfers shall be conducted as follows:

(a) At scheduled intermediate stops where special nuclear material is not scheduled for transfer, the guard shall observe the opening of the cargo compartment and assure that the shipment is not removed. The guard shall maintain continuous visual surveillance of the cargo compartment. Continuous visual surveillance of the cargo compartment shall be maintained up to the time the vehicle is ready to depart. The guard shall observe the vehicle until it has departed, and shall notify the licensee or his agent of the latest status immediately thereafter.

(b) At points where special nuclear material is transferred from a vehicle to storage, from one vehicle to another, or from storage to a vehicle, the guard shall keep the shipment under con-

tinuous visual surveillance by observing the opening of the cargo compartment of the incoming vehicle and assuring that the shipment is complete by checking locks and/or seals. Continuous visual surveillance of a shipment shall be maintained at all times it is in the terminal or in storage. Shipments shall be preplanned in order to avoid storage times in excess of 24 hours. Continuous visual surveillance of the cargo compartment shall be maintained up to the time the vehicle is ready to depart from the terminal. The guard shall observe the vehicle until it has departed, and shall notify the licensee or his agent of the latest status immediately thereafter.

(c) The guard shall be required to immediately notify the carrier and the licensee who made the arrangements for protection of special nuclear material of any deviation from or attempted interference with schedule or routing.

(d) This section is effective March 6, 1974.

§ 73.36 Miscellaneous requirements.

(a) Each licensee who takes delivery of special nuclear material free on board (f.o.b.) the point at which it is delivered to a carrier for transport shall make the arrangements to assure that such special nuclear material will be protected in transit as prescribed in §§ 73.30 through 73.35, rather than the person who delivers such shipment to the carrier for transport.

(b) Each licensee who imports special nuclear material shall make arrangements to assure that such material will be protected in transit as follows:

(1) An individual designated by the licensee or his agent, or as specified by a contract of carriage, shall confirm the container count and examine locks and/or seals for evidence of tampering, at the first place in the United States at which the shipment is discharged from the arriving carrier.

(2) The shipment shall be protected at the first terminal at which it arrives in the United States and all subsequent terminals as provided in §§ 73.30 through 73.35 and paragraphs (c) and (f) of this section.

(c) (1) Each licensee who delivers special nuclear material to a carrier for transport shall immediately notify the consignee by telephone, telegraph, or teletype, of the time of departure of the shipment, and shall notify or confirm with the consignee the method of transportation, including the names of carriers, and the estimated time of arrival of the shipment at its destination. (2) In the case of a shipment free on board (f.o.b.) the point where it is delivered to a carrier for transport, each licensee shall, before the shipment is delivered to the carrier, obtain written certification from the licensee who is to take delivery of the shipment at the f.o.b. point that the physical protection arrangements required by §§ 73.30 through 73.35 for licensed shipments have been made. When a contractor exempt from the requirements for a Commission license is the consignee of a shipment, the licensee shall, before the shipment is delivered to the carrier, obtain written certification from the contractor who is to take delivery of the shipment at the f.o.b. point that the physical protection arrangements required by ERDA Manual or NRC Manual Chapters 2401 or 2405, as appropriate, have been made.

(3) Each licensee who delivers special nuclear material to a carrier for transport shall also make arrangements with the consignee to be notified immediately by telephone, telegraph, or teletype, of the arrival of the shipment at its destination.

(d) In addition to complying with the requirements specified in paragraphs (c) and (f) of this section, each licensee who exports special nuclear material shall comply with the requirements specified in §§ 73.30 through 73.35, as applicable, up to the first point where the shipment is taken off the vehicle outside the United States. The licensee shall also make arrangements with the consignee to be notified immediately by telephone and telegraph, teletype, or cable, of the arrival of the shipment at its destination, or of any such shipment that is lost or unaccounted for after the estimated time of arrival at its destination.

(e) Each licensee who receives a shipment of special nuclear material shall immediately notify the person who delivered the material to a carrier for transport of the arrival of the shipment at its destination. In the event such a shipment fails to arrive at its destination at the estimated time, the consignee, if a licensee, or in the case of an export shipment, the licensee who exported the shipment, shall immediately notify by telephone and telegraph, or teletype, the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of this part, and the licensee or other person who delivered the material to a carrier for transport. The licensee who made the physical protection arrangements shall also immediately notify by telephone and telegraph, or teletype the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional office listed in Appendix A of the action being taken to trace the shipment.

(f) Each licensee who makes arrangements for physical protection of a shipment of special nuclear material as required by §§ 73.30 through 73.36 shall immediately conduct a trace investigation of any shipment that is lost or unaccounted for after the estimated arrival time and file a report with the Commission as specified in § 73.71. If the licensee who conducts the trace investigation is not the consignee, he shall also immediately report the results of his investigation by telephone and telegraph, or teletype to the consignee.

(g) Paragraphs (a), (b), (c) and (d) of this section are effective March 6, 1974.

PHYSICAL PROTECTION REQUIREMENTS AT FIXED SITES

§ 73.40 Physical protection: General requirements at fixed sites.

Each licensee shall provide physical protection against industrial sabotage and against theft of special nuclear material at the fixed sites where licensed activities are conducted. Security plans submitted to the Atomic Energy Commission for approval shall be followed by the licensee after March 6, 1974.

§ 73.50 Requirements for physical protection of licensed activities.

In addition to any other requirements of this part, each licensee who is authorized to operate a fuel reprocessing plant pursuant to Part 50 of this chapter or who possesses or uses uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233, or plutonium alone or in any combination in a quantity of 5000 grams or more computed by the formula, grams = (grams contained J-235) + 2.5 (grams U-233 + grams plutonium), other than in the operation of a nuclear reactor licensed pursuant to Part 50 of this chapter, shall comply with the following.

(a) *Physical security organization.* (1) The licensee shall establish a security organization, including guards, to protect his facility against industrial sabotage and the special nuclear material in his possession against theft.

(2) At least one supervisor of the security organization shall be on site at all times.

(3) The licensee shall establish, maintain and follow written security procedures which document the structure of the security organization and which detail the duties of guards, watchmen, and other individuals responsible for security.

(4) The licensee shall not permit an individual to act as a guard or watchman unless such individual has been properly trained and equipped and has qualified by demonstrating: (i) An understanding of the licensee's security procedures, and (ii) the ability to execute all duties required of him by such procedures. Each guard and watchman shall be requalified at least annually. Such requalification shall be documented.

(b) *Physical barriers.* (1) The licensee shall locate vital equipment only within a vital area, which, in turn, shall be located within a protected area such that access to vital equipment requires passage through at least two physical barriers. More than one vital area may be within a single protected area.

(2) The licensee shall locate material access areas only within protected areas such that access to the material access area requires passage through at least two physical barriers. More than one material access area may be within a single protected area.

(3) The physical barrier at the perimeter of the protected area shall be separated from any other barrier designated as a physical barrier within the protected area, and the intervening space monitored or periodically checked to detect the presence of persons or vehicles so that the facility security organization can respond to suspicious activity or to the breaching of any physical barrier.

(4) An isolation zone shall be maintained around the physical barrier at the perimeter of the protected area and any part of a building used as part of that physical barrier. The isolation zone shall

APPENDIX D-5

NUCLEAR REGULATORY COMMISSION

10 CFR 20.205. Procedures for Picking Up, Receiving, and Opening Packages.

§ 20.205 Procedures for picking up, receiving, and opening packages.

(a) (1) Each licensee who expects to receive a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section shall:

(i) If the package is to be delivered to the licensee's facility by the carrier, make arrangements to receive the package when it is offered for delivery by the carrier; or

(ii) If the package is to be picked up by the licensee at the carrier's terminal, make arrangements to receive notification from the carrier of the arrival of the package, at the time of arrival.

(2) Each licensee who picks up a package of radioactive material from a carrier's terminal shall pick up the package expeditiously upon receipt of notification from the carrier of its arrival.

(b) (1) Each licensee, upon receipt of a package of radioactive material, shall monitor the external surfaces of the package for radioactive contamination caused by leakage of the radioactive contents, except:

(i) Packages containing no more than the exempt quantity specified in the table in this paragraph;

(ii) Packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125;

(iii) Packages containing only radioactive material as gases or in special form;

(iv) Packages containing only radioactive material in other than liquid form (including Mo-99/Tc-99m generators) and not exceeding the Type A quantity limit specified in the table in this paragraph; and

(v) Packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries.

The monitoring shall be performed as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or eighteen hours if received after normal working hours.

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify the final delivering carrier and, by telephone and telegraph, the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group [1]	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
I	.01	0.001
II	0.1	0.050
III	1	3
IV	1	20
V	1	20
VI	1	1000
VII	25,000	1000
Special Form	1	29

(c) (1) Each licensee, upon receipt of a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section, other than those transported by exclusive use vehicle, shall monitor the radiation levels external to the package. The package shall be monitored as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or 18 hours if received after normal working hours.

(2) If radiation levels are found on the external surface of the package in excess of 200 millirem per hour, or at three feet from the external surface of the package in excess of 10 millirem per hour, the licensee shall immediately notify, by telephone and telegraph, the final delivering carrier and the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

(d) Each licensee shall establish and maintain procedures for safely opening packages in which licensed material is received, and shall assure that such procedures are followed and that due consideration is given to special instructions for the type of package being opened.

APPENDIX E.

POPULATION DOSE FORMULAS FOR NORMAL TRANSPORT

The basic formulation for the assessment of population dose is based upon an analysis contained in NSS 8172.2*. The results derived in the report (hereafter called NSS) are based upon an expression for dose rate as a function of distance from a shipment of radioactive material. In NSS it was assumed that the shipment was sufficiently small that the radiation appeared to emanate from point sources. This is an acceptable approximation for distances between the receptor and source of approximately two source characteristic lengths. At smaller distances, the point source formula over-predicts exposure and, therefore, will provide a conservative (too high) estimate of dose. The dose rate formulation is given by:

$$D(r) = K \frac{B(r)\ e^{-\mu r}}{r^2}$$

where $D(r)$ = dose rate in mrem/hr

K = dose rate factor

$B(r)$ = Berger buildup factor

μ = absorption coefficient for air 1.05×10^{-4} (cm^{-1})

r = distance from source (cm)

Because the NSS study was devoted to large shipments of nuclear fuel cycle products in exclusive use vehicles, the assumption adopted in the report was that a 200 mrem/hr dose rate occurs at the vehicle's outer surface (assumed to be 3 feet from the shipment vehicle centerline). To achieve this dose rate, K takes the value 1.67×10^6 mrem/hr. The dose rate

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*"Evaluation of Routine Exposure from the Shipment of Radioactive Material for the Nuclear Power Industry" a Holmes and Narver Inc. Nuclear and Systems Science Group Report, NSS 8172.2, prepared for the USEPA under contract No. 68-01-2101, September, 1974.

versus distance obtained from this formula are shown in Figure E-1.

From Figure E-1 it is seen that if the source of radiation were in a package with a distance of 1.2 feet from the source to the nearest surface, the package TI rating would be approximately 100 TI. In subsequent developments, where single packages rather than shipments are involved, this single package equivalent TI rating will be used to normalize dose rates to unity transport index.

A. Dose to Surrounding Population While Moving

Using Equation 1 the integrated person-rem, was calculated in NSS for an area Y kilometers on each side of, and 1 kilometer in each direction along the transport link. The area was occupied by people at a density of 1 person/km^2 and the vehicle was assumed to move at a speed of 80 km/hr. In such an area having a half-width, Y = 0.8 km, 10^{-6} person-rem/shipment kilometer/unit population density was found by integration to be the accumulated population dose. To calculate the population dose for other situations, the following formulation for population dose PD_m is found:

$$PD_m = 10^{-6} \left(\frac{\text{person-rem}}{(\text{shipment-km})(\text{unit population density})} \right) * P \cdot N_{ss} \cdot L \, \frac{80}{V}$$

where P = population density in persons/km^2
N_{ss} = number of shipments (200 mr/hr surface dose)
L = length of travel (km)
V = transport speed in (km/hr)

Converting the units in this expression to a form compatible with this study yields the following equation:

$$PD'_m = 3.1 \times 10^{-7}\ P' \cdot L' / V'_s \cdot N_s \cdot TI \qquad (2)$$

where P' = population density (people/mi^2)
L' = distance travelled/shipment (miles)
V'_s = shipment speed (mi/hr)
N_s = number of shipments/yr
TI = TI per shipment
PD' = person-rem/yr

The manner in which PD' varies with Y, the distance on each side of the transport link which receives the dose, is such that about half of the population dose is received within the first 100 meters on each side of the transport link. Thus, in hilly areas or in cities where there is significant shielding from terrain or buildings, the doses received are likely to be smaller by a factor of approximately two.

By transforming equation 2 from a moving to a stationary shipment context, the dose to surrounding population is obtained. The quantity L/V is replaced by stop time T(in hours/shipment) to obtain:

$$PD_s = 3.1 \times 10^{-7}\ P' \cdot N_s \cdot TI \cdot T \qquad (3)$$

B. Dose to Population on Transport Link

Using the dose-distance relation given in Equation 2, the mean dose rate received at a point during the approach of a shipment on a path which passes within a distance d(feet), of the receptor point was calculated and is shown in Figure E-2. The dose, D_R, experienced by a vehicle moving relative to the shipment is given by:

$$D_P = 6 \times 10^{-4} \left(\frac{\text{mrem-mi}}{\text{mrem-shipment}} \right) \bar{D}(d)/V_R \quad \text{rem/shipment}$$

where D_R = the total dose received in passing a shipment (200 mrem/hr at surface)

$\bar{D}(d)$ = the mean dose rate from Figure E-2 in passing a distance d from the shipment (mrem/hr)

V_R = the relative velocity between the vehicle and shipment (mph)

With the dose rate for a shipment corresponding approximately to a 100 TI package, D_R becomes:

$$D_R = 6 \times 10^{-6} \bar{D}(d)/V_R \quad \text{rem/TI} \qquad (4)$$

To evaluate the dose to population using the transport link, the number of vehicles exposed must be determined. The total number of vehicles/mile on a road in one direction is:

$$N_r = \frac{KN}{48V_T}$$

where K traffic factor = 2 for day time, 4 for rush hour

N = number of vehicles/day

V_T = traffic speed (mph)

If Vs is shipment speed (mph), the number of vehicles exposed during a length of shipment travel, $\bar{L}$, is:

(a) in oncoming lanes $\frac{KN}{48} \left(\frac{1}{V_T} + \frac{1}{V_s} \right) \bar{L} = N_o$

(b) in following lanes $\frac{KN}{48} \left(\frac{1}{V_T} - \frac{1}{V_s} \right) \bar{L} = N_f$

The total dose received by passengers within the vehicles is given by:

$$D_T = N_o \cdot \left[\frac{6 \times 10^{-6}\ \bar{D}(do)}{V_R} + N_f \cdot \frac{6 \times 10^{-6}\ \bar{D}(df)}{V_R} \right] S \cdot TI \cdot N_s$$

The factor S is the number of people per car. After some algebraic manipulation, D_T becomes:

$$D_T = 6 \times 10^{-6} \frac{KNS}{24} \left(\frac{\bar{D}(d_o) + \bar{D}(d_f)}{2} \right) \frac{N_s \cdot TI \cdot \bar{L}}{V_T V_s} \quad \text{(person-rem)} \quad (5)$$

Here $\bar{D}(d_c)$ is the mean dose rate in oncoming traffic lanes a distance d_o from the shipment's lane. Similarly, $\bar{D}(d_f)$ is the mean dose in following lanes a distance d_f from the shipment's lane. Some representative values for $\frac{1}{2}(\bar{D}(d_o) + \bar{D}(d_f))$ in Equation 5 are:

2 lane roads	1.4×10^{-1}	mrem/hr
4 lane roads	9×10^{-2}	mrem/hr
4 lane freeway	$7\text{-}8 \times 10^{-2}$	mrem/hr

C. Input Data for Dose Calculation

Table E-1 provides a complete list of all parameters used in the expression to evaluate population dose as well as other parameters used in the normal transport model.

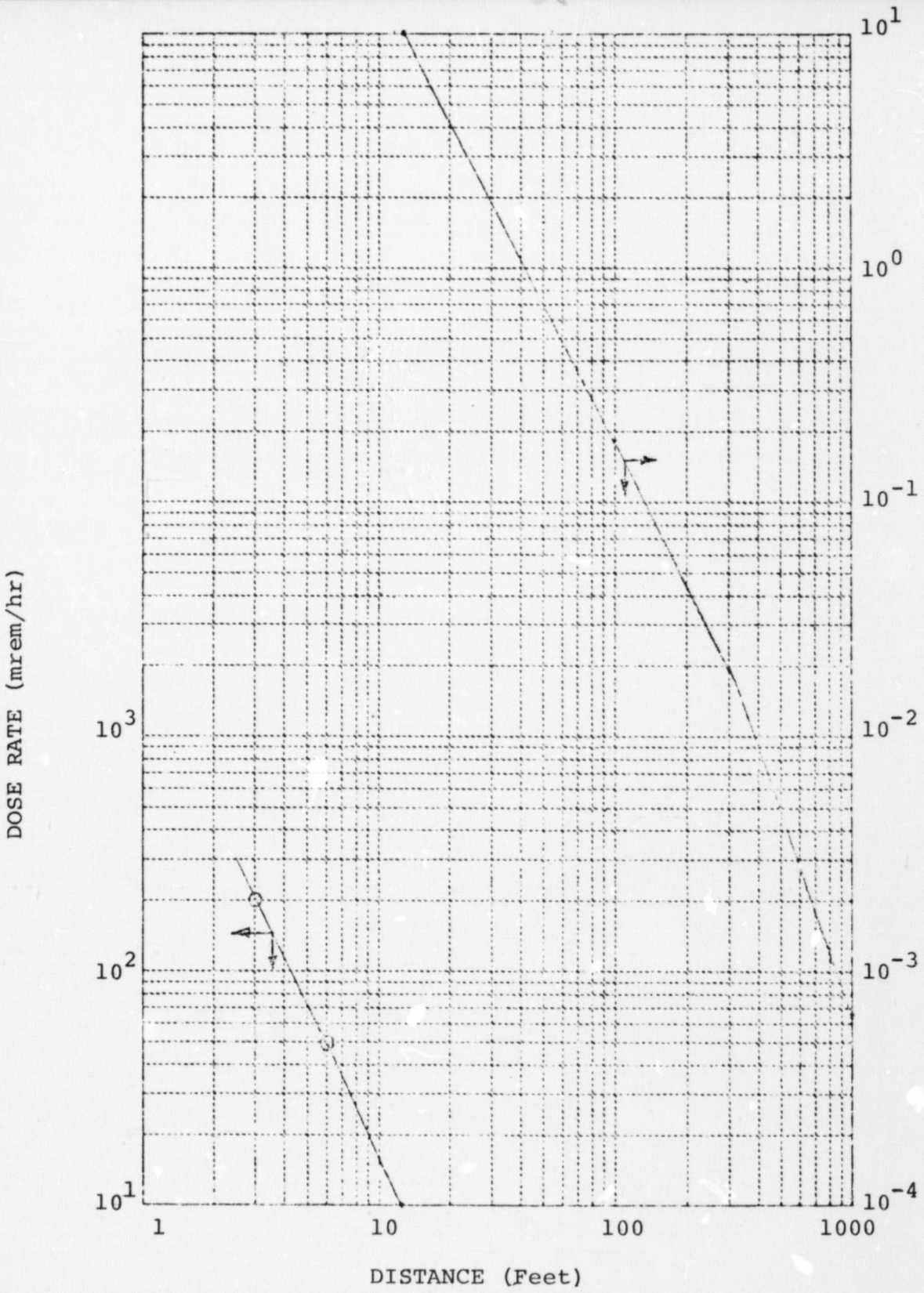


FIGURE E-1 Dose rate versus distance for a point source of radiation normalized to 200 mrem/hr at 3 feet from the source.

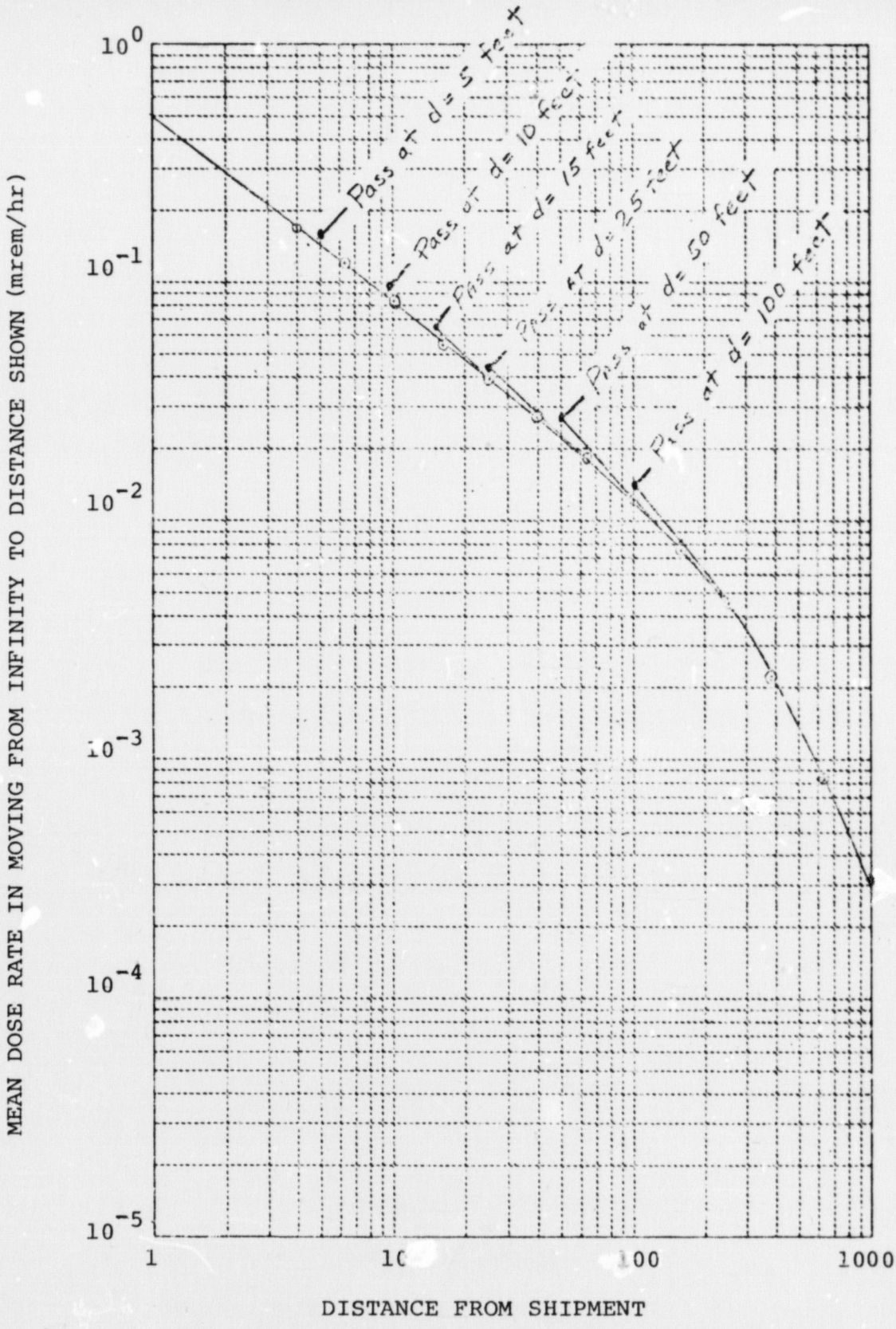


FIGURE E-2 Mean dose rate obtained in moving from infinity to the distance indicated and in passing at the distance indicated.

TABLE E-1

INPUT PARAMETERS FOR NORMAL TRANSPORT CALCULATION OF POPULATION DOSE TO RADIATION

DOSE INFORMATION	TRUCK	P. VAN PASS. AIR	CARGO AIR	RAIL	SHIP	BARGE	HELICOPTER	AIR TAXI	C. VAN
NUMBER OF CREWMEN	2.00E+00	1.00E+00	2.00E+00	3.00E+00	5.00E+00	0.	2.00E+00	2.00E+00	0.	1.00E+00
MEAN VELOCITY WHILE TRAVELING ABOARD	4.50E+01	4.50E+01	4.26E+02	4.26E+02	5.00E+01	0.	1.50E+01	0.	0.	4.50E+01
TI-DOSERATE CONVERSION FACTOR FOR CREW COMPARTMENT (REM-HR/TI)	2.00E-01	2.00E-01	1.00E-03	1.00E-03	2.00E-03	0.	2.00E-03	2.00E-01	0.	2.00E-01
TI-DOSERATE CONVERSION FACTOR FOR WAREHOUSE	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	0.	0.	0.	0.	1.00E-04
NUMBER OF PASSENGERS PER FLIGHT	0.	0.	6.00E+01	0.	0.	0.	0.	5.00E+00	0.	0.
TI-DOSERATE CONVERSION FACTOR FOR PASSENGER COMPARTMENT	0.	0.	3.00E-02	0.	0.	0.	0.	0.	0.	0.
NUMBER OF HANDLINGS	2.00E+00	2.00E+00	4.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00
TOTAL LENGTH OF TRIP PER TRIP (KM)	1.00E+00	5.00E-01	0.	0.	0.	0.	1.00E+01	0.	0.	5.00E-01
TOTAL LENGTH OF TRIP STOPS PER TRIP (HR)	5.00E+00	0.	1.00E+00	1.00E+00	0.	0.	0.	5.00E-01	0.	0.
TOTAL LENGTH OF TRIP STOPS PER TRIP (HR)	2.00E+00	0.	0.	0.	6.00E+00	0.	0.	0.	0.	0.
FRACTION OF TRAVEL/ACCIDENTS IN HIGH POP. ZONE	5.00E-02	4.30E-01	7.00E-02	7.00E-02	5.00E-02	0.	5.00E-02	0.	0.	4.00E-01
VELOCITY IN HIGH POP. ZONE	1.50E+01	1.50E+01	0.	0.	1.50E+01	0.	5.00E+00	0.	0.	1.50E+01
FRACTION OF TRAVEL/ACCIDENTS IN MEDIUM POP. ZONE	5.00E-02	6.00E-01	7.00E-01	7.00E-01	5.00E-02	0.	0.	0.	0.	6.00E-01
VELOCITY IN MEDIUM POP. ZONE	2.50E+01	2.50E+01	0.	0.	4.00E+01	0.	0.	0.	0.	2.50E+01
FRACTION OF TRAVEL/ACCIDENTS IN LOW POP. ZONE	9.00E-01	0.	2.30E-01	2.30E-01	9.00E-01	0.	0.	0.	0.	0.
VELOCITY IN LOW POP. ZONE	5.50E+01	5.50E+01	0.	0.	6.00E+01	0.	0.	0.	0.	5.50E+01
FRACT. OF TRAVEL IN HIGH POP. ZONE DURING RUSH HOUR TRAFFIC	8.00E-02	8.00E-02	0.	0.	0.	0.	0.	0.	0.	8.00E-02
FRACT. OF TRAVEL IN HIGH POP. ZONE DURING NORMAL TRAFFIC	9.20E-01	9.20E-01	0.	0.	0.	0.	0.	0.	0.	9.20E-01
FRACT. OF TRAVEL ON CITY STREETS	5.00E-02	6.50E-01	0.	0.	1.00E+00	0.	0.	0.	0.	6.50E-01
FRACT. OF TRAVEL ON 2-LANE ROADS	0.	5.00E-02	0.	0.	0.	0.	0.	0.	0.	5.00E-02

TABLE E-1 (Cont'd)

FRACT. OF TRAVEL ON 4-LANE ROADS	1.00E-01	5.00E-02	0.	0.	0.	0.	0.	0.	0.	5.00E-02
FRACTION OF TRAVEL ON FREEWAYS /INTERSTATES	8.00E-01	2.00E-01	0.	0.	0.	0.	0.	0.	0.	2.00E-01
TRAFFIC COUNT PASSING A SPECIFIC POINT--LPOP	5.00E+03	5.00E+03	0.	0.	1.00E+00	0.	0.	0.	0.	5.00E+03
TRAFFIC COUNT PASSING A SPECIFIC POINT--MPOP	1.00E+04	1.00E+04	0.	0.	1.00E+01	0.	0.	0.	0.	1.00E+04
TRAFFIC COUNT PASSING A SPECIFIC POINT--HPOP	3.00E+04	3.00E+04	0.	0.	3.00E+01	0.	0.	0.	0.	3.00E+04
NUMBER OF PEOPLE PER VEHICLE	2.00E+00	2.00E+00	0.	0.	1.00E+02	0.	0.	0.	0.	2.00E+00
NUMBER OF ATTENDENTS PER FLIGHT	0.	0.	4.00E+00	0.	0.	0.	0.	0.	0.	0.
TI-DOSE CONVERSION FACTOR FOR ATTENDENTS	0.	0.	2.80E-02	0.	0.	0.	0.	0.	0.	0.
STORAGE TIME	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00
PERSON DENSITY-STORAGE	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03

APPENDIX F

PRODUCTION OF A NUCLEAR EXPLOSION BY AMATEURS - POTENTIAL AND CONSEQUENCES

A complete review of the safeguards problem must include consideration of the potential consequences of safeguards failures. A successful theft of sufficient quantities of special nuclear material could lead to the use of explosive or radiological weapons.

Fabrication of a Nuclear Explosive by Amateurs

The debate on whether or not construction of a nuclear explosive device is easy revolves around matters of degree. There appears to be general agreement that, given the availability of the requisite nuclear material, the construction of an illicit explosive device requires a certain level and range of skills and resources. Disagreement arises with respect to the way the level of required skills and resources are characterized.

A theoretical knowledge of nuclear physics and the unclassified literature on how nuclear weapons work are not a sufficient basis for the confident design of a practical nuclear explosive. The critical knowledge required for designing and fabricating a reasonably reliable nuclear explosive is not theory; it is the practical experience in design, fabrication and testing of actual nuclear devices -- the experience of having tried and experimentally determined what will and will not work and why. This kind of knowledge is not widespread.

The assembly of a workable weapon is complex and laden with many obstacles, any one of which could prevent the

accomplishment of the adversary's first goal -- the availability of a workable explosive device. The attempted detonation of even high-grade material is more likely to result in a low tonnage yield or a disassembling, non-nuclear explosion than a substantial yield explosion unless the fabrication and assembly have been carried out by highly trained and experienced technicians.

Considering the sequence of goals that must be attained by the adversary, the overall probability of any successful explosion of an illicit weapon is low. That such a weapon would be in the multikiloton range is doubtful. Nevertheless, the potential consequences arising from any nuclear explosive are so serious as to warrant the utmost vigilance, however low the probabilities may be. With time, simple "recipes" for crude nuclear explosives that might just work could pass into the public domain from the minds of experienced weapon makers. Thus, it is essential that nuclear materials be safeguarded so as to prevent unauthorized access to or acquisition of any significant quantities of nuclear materials that could be employed in the fabrication of a nuclear explosive.

The physical effects of a nuclear blast can be determined from the published literature. A summary of these physical effects is given by Willrich and Taylor. The damage radii for various effects of nuclear explosions as functions of yield are shown in Table F-1 of this section.

Examples are given by Willrich and Taylor to illustrate the effects of nuclear explosions in a football stadium, a residential area, or a basement parking lot. While the examples given are speculative and are based on an assumption of complete success by the adversary, they do illustrate the extremely severe consequences of a nuclear explosion.

Table F-1

DAMAGE RADII FOR VARIOUS EFFECTS OF NUCLEAR EXPLOSIONS AS FUNCTIONS OF YIELD[a]

Yield (high explosive equivalent)	Radius for Indicated Effect (Meters)						
	500-rem Prompt Gamma Radiation	500-rem Neutrons	Fallout (500-rem Total Dose)[b]	Severe Blast Damage (10 pst)	Moderate Blast Damage (3 pst)	Crater Radius (surface burst)	Crater Radius (underground burst)
1 ton	45	120	30-100	33	65	3.4	6.7
10 tons	100	230	100-300	71	140	6.8	13.3
100 tons	300	450	300-1,000	150	300	13.6	26.5
1 kiloton	680	730	1,000-3,000	330	650	27	53
10 kilotons	1,150	1,050	3,000-10,000	710	1,400	54	104
100 kilotons	1,600	1,450	10,000-30,000	1,500	3,000	108	208
1 megaton	2,400	2,000	30,000-100,000	3,250	6,500	216	416

[a]M. Willrich and T. B. Taylor, Nuclear Theft: Risks and Safeguards, Ballinger Pub. Co., Cambridge, Mass., 1974.

[b]Assuming 1-hr exposure to fallout region, for yields less than 1 kiloton, increasing to 12 hr for 1 megaton.

Clearly, if a workable illicit device of even modest yield were cleverly placed and detonated, thousands of people could be killed and millions of dollars worth of property could be destroyed. For reasons stated earlier, the probability that any of these events would actually take place, while not specifically quantifiable, is considered to be extremely low. It should be further noted that the adversary who has succeeeded in fabricating a workable weapon, despite the obstacles cited above, faces further serious obstacles if his goal is to cause a high number of casualties and great damage. The selection of a appropriate emplacement areas is finite; the safeguards response capability, alerted by the theft or diversion, would have brought its search and detection techniques to bear; and law enforcement agencies would be watchful for suspicious actions, especially in congested urban areas, at public gatherings, at key governmental facilities, and in areas of technological vulnerability.

Dispersal Weapons

The treatment of the consequences of radiological weapons is more speculative than that for nuclear explosions because of the greater extent of uncertainty involved. Detailed discussions of the subject of dispersal of plutonium are contained in References 1 and 2 to Chapter VI (WASH-1327 and WASH-1535). In summary it can be said that the possibility exists that plutonium could be dispersed into buildings or the atmosphere (as could most any chemical, radiological or biological agent). Although the potential consequences could be significant they would not approach the severity of a nuclear explosive. The use of radiological weapons does not appear to be consistent with the observed behavior of terrorists or extortionists.*

*Willrich and Taylor

APPENDIX G

SENSITIVITY ANALYSIS

A. Introduction

A sensitivity analysis was performed on the model used for this assessment to determine if the selection of any one specific model parameter was unusually significant from the point of view of effect on laten cancer fatalities due to normal transport (LCF_{normal}), latent cancer fatalities due to accidents during transport ($LCF_{accident}$), or annual early fatality probability.

B. Theoretical Basis

The sensitivity analysis is based on the following:

$$\Delta I \cong \lim_{\Delta x_i \to 0} \sum_{i=1} \frac{\partial I}{\partial x_i} \Delta x_i \qquad (1)$$

where I = environmental impact of a parameter as a function of $x_1, x_2, \ldots x_n$

x_i = variables whose variations are being considered.

In the case of a single variable parameter (such as number of passengers per flight), equation (1) reduces to the identity:

$$\Delta I \cong \frac{dI}{dx} \Delta x \qquad (2)$$

In the case of a parameter of several variables (such as the proportion of truck travel in the three population zones), equation (1) can be rewritten as:

$$\Delta I \cong \lim_{\Delta x_1 \to 0} \frac{\partial I}{\partial x_1} \Delta x_1 + \lim_{\Delta x_2 \to 0} \frac{\partial I}{\partial x_2} \Delta x_2 + \lim_{\Delta x_3 \to 0} \frac{\partial I}{\partial x_3} \Delta x_3 \qquad (3)$$

where x_i = proportion of truck travel in ith population zone.

C. Analysis and Results

Each variable within the model was increased by 10 percent and the percent increase in environmental impact was calculated. Although there are dependencies between variables within the model, it was found that ΔI could be accurately approximated (and more readily computed) when these dependencies were not taken into account.

The effect on LCF_{normal}, $LCF_{accident}$, and annual early fatality probability resulting from the 10 percent parameter increases are plotted in Figures G-1, G-2, and G-3. Parameters or variables not plotted had a lower sensitivity than the smallest value plotted.

The sensitivity analysis did not include analysis of data such as number of shipments, mileages per shipment, mode splits between isotopes, etc., since this data is not a part of the model as such. The calculated impact is very sensitive to any change, particularly for changes involving secondary modes. However, it was felt that the baseline data

model should be held constant to evaluate sensitivities in model parameters.

The results show that the most sensitive parameter for LCF_{normal} or $LCF_{accident}$ is urban population density. A 10 percent increase in that value results in a 6.6 percent increase in LCF_{normal} and a 5.5 percent increase in $LCF_{accident}$. In the case of annual early fatality probability, the most sensitive parameter is the proportion of air travel/accidents in or over medium population zones where a 10 percent parameter increase yields a 6.5 percent impact.

FIGURE G-1. Sensitivity of LCF_{normal} to Increases in Model Parameters

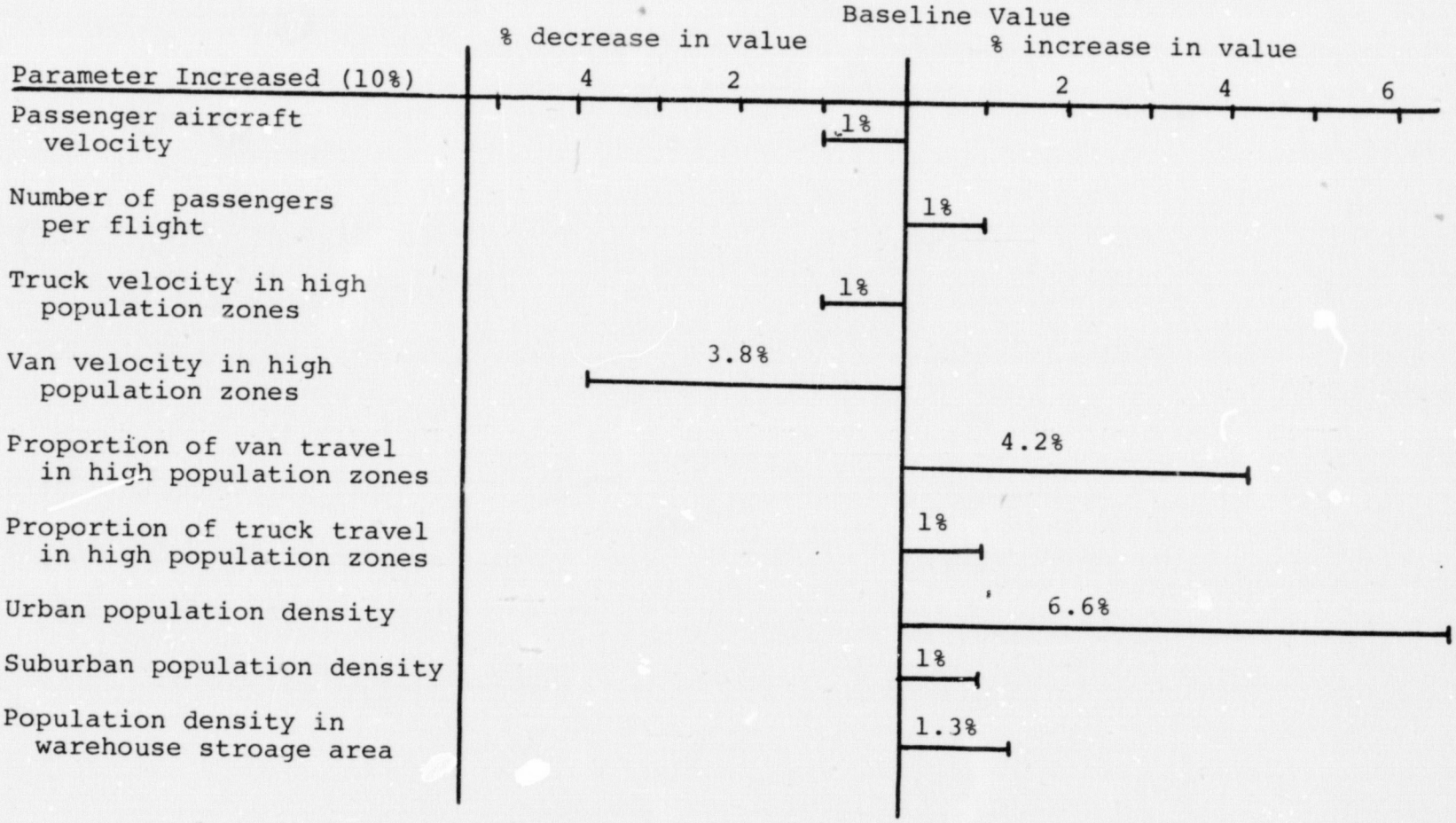


FIGURE G-2. Sensitivity of $LCF_{accident}$ to Increases in Model Parameters

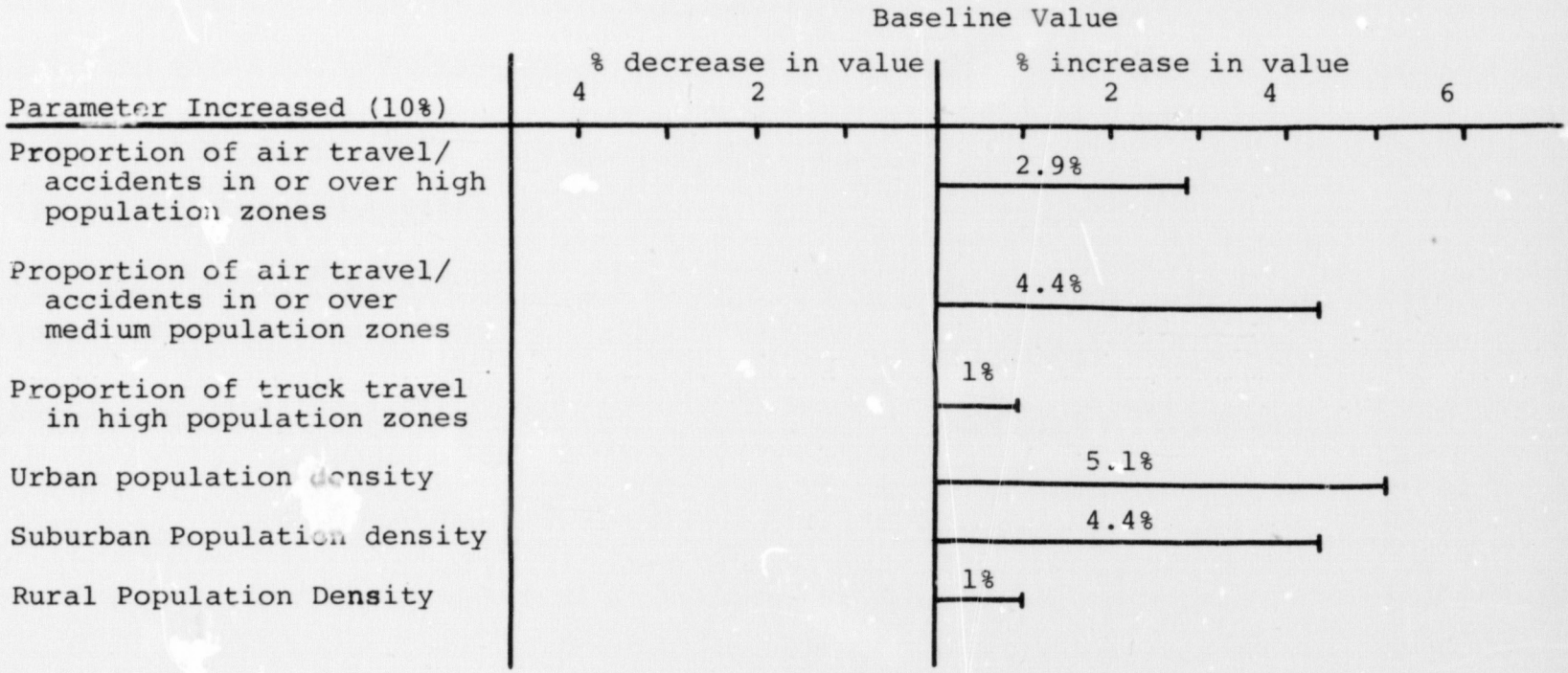
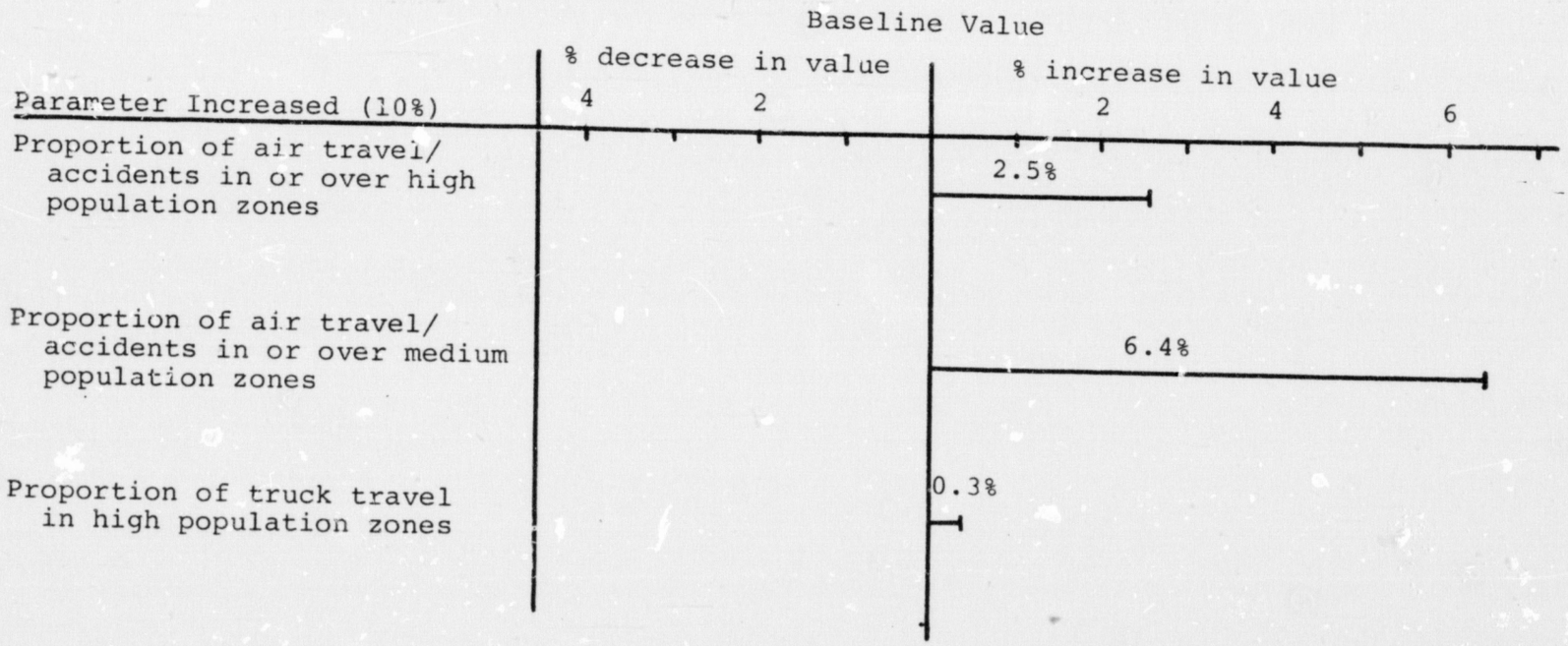


FIGURE G-3. Sensitivity of Annual Early Fatality Probability to Increases in Model Parameters



New Jersey Department of Environmental Protection
New Mexico Environmental Improvement Agency
New York Department of Environmental Conservation
New York Department of Labor
New York Bureau of Radiological Health
New York City Department of Health
North Carolina Department of Human Resources
North Dakota Department of Health
Ohio Department of Health
Oklahoma Department of Health
Oregon Department of Human Resources
Pennsylvania Department of Environmental Resources
Puerto Rico Department of Health
Rhode Island Department of Health
South Carolina Department of Health and Environmental Control
South Dakota Department of Health
Tennessee Department of Public Health
Texas Department of Health Resources
Utah Division of Health
Vermont Department of Health
Virginia Department of Health
Virgin Islands Department of Health
Washington Department of Social and Health Services
West Virginia Department of Health
Wisconsin Department of Health and Social Services
Wyoming Department of Health and Social Services

APPENDIX H

STATE AND LOCAL REGULATORY AGENCIES

Alabama Department of Public Health
Alaska Department of Health and Social Services
Arizona Atomic Energy Commission
Arkansas Department of Health
California Department of Health
Colorado Department of Health
Connecticut Department of Environmental Protection
Delaware Division of Public Health
District of Columbia Environmental Health Administration
Florida Division of Health
Georgia Department of Human Resources
Hawaii Department of Health
Idaho Department of Health and Welfare
Illincis Department of Public Health
Indiana State Board of Health
Iowa Department of Environmental Quality
Kansas Department of Health and Environment
Kentucky Department for Human Resources
Louisiana Division of Radiation Control
Maine Department of Health and Welfare
Maryland Department of Health and Mental Hygiene
Massachusetts Department of Public Health
Michigan Department of Public Health
Minnesota Department of Health
Mississippi Board of Health
Missouri Department of Social Services
Montana Department of Health and Environmental Sciences
Nebraska Department of Health
Nevada Department of Health and Welfare
New Hampshire Division of Public Health Services

CERTIFICATE OF SERVICE

I hereby certify that a copy of the foregoing Supplemental Appendix Volume II was served on counsel for defendants this 2nd day of June, 1976.

JOHN F. SHEA, III
Assistant Attorney General